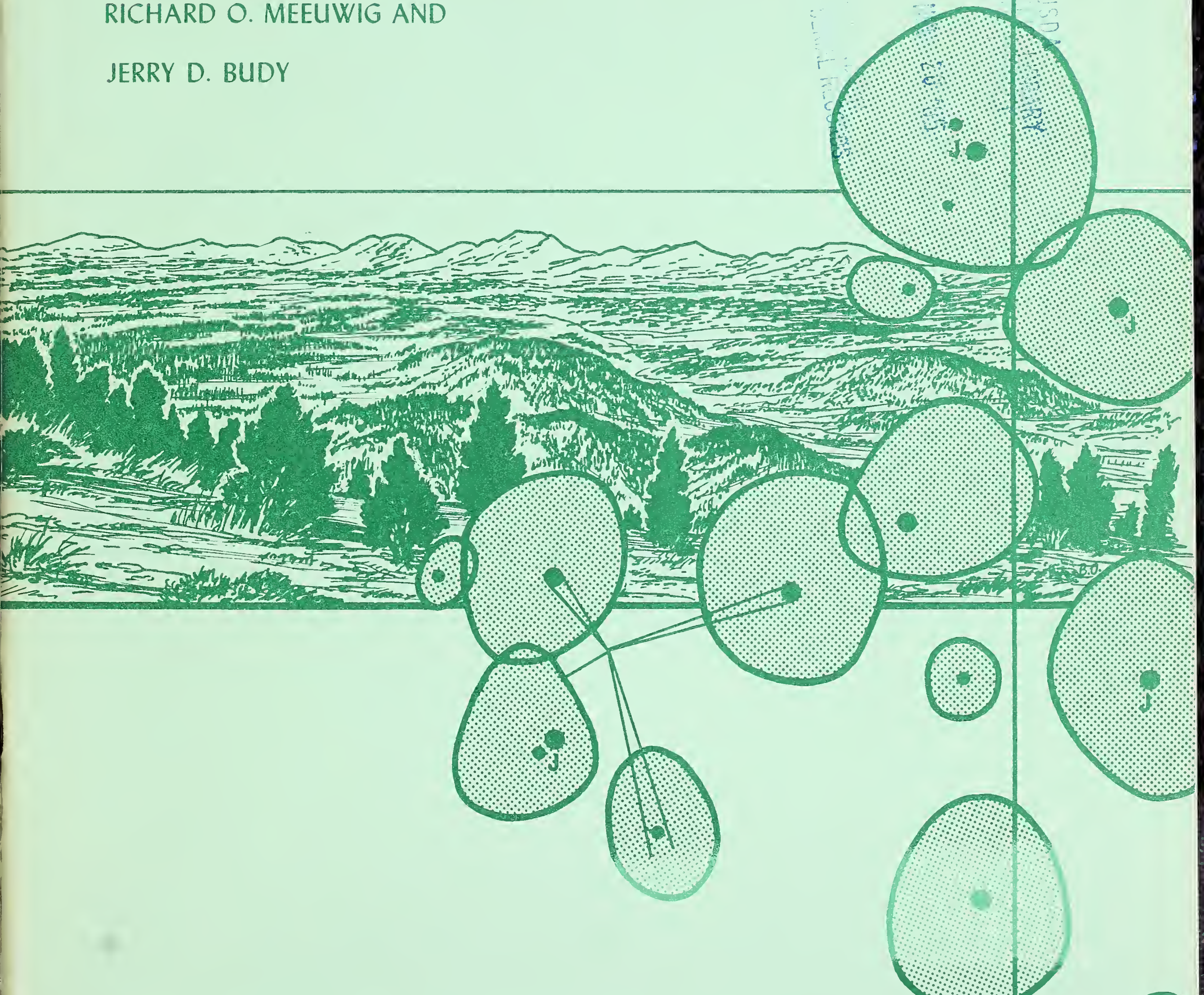
POINT AND LINE-INTERSECT SAMPLING IN PINYON-JUNIPER WOODLANDS

RICHARD O. MEEUWIG AND

JERRY D. BUDY



USDA Forest Service General Technical Report INT-104
Intermountain Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

THE AUTHORS

RICHARD O. MEEUWIG is a research forester and leader of the Intermountain Station's pinyon-juniper ecology and management research work unit at the Renewable Resources Center, University of Nevada Reno. He has B.S. and M.S. degrees in forestry from the University of California Berkeley and a Ph.D. in soil physics from Utah State University.

JERRY D. BUDY is assistant professor of forestry in the Division of Renewable Natural Resources, Max C. Fleischmann College of Agriculture, University of Nevada Reno. He has a B.S. from the University of Wisconsin and is completing requirements for a Ph.D. in forest hydrology at the University of Nevada Reno.

RESEARCH SUMMARY

Two probability proportional to size (p.p.s.) sampling methods have been adapted for use in pinyon-juniper woodlands. Procedures are described for estimating biomass, stand basal area, canopy cover, tree density, and growth rates using either point sampling or line-intersect sampling. Both sampling methods are supported by regression equations for estimating aboveground biomass, cordwood, slash, fine fuels, and foliage of singleleaf pinyon and Utah juniper. Regression equations for predicting decadal growth rates in terms of stand basal area, aboveground biomass, and cordwood are also presented. These procedures can be modified for use with other woodland species.

USDA Forest Service
General Technical Report INT-104
February 1981

POINT AND LINE-INTERSECT SAMPLING IN PINYON-JUNIPER WOODLANDS

Richard O. Meeuwig and Jerry D. Budy

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Ogden, Utah 84401

CONTENTS

INTRODUCTION

Although pinyon-juniper woodlands cover vast areas in the western United States, little attention has been given to assessing their wood resources until recently. Volume tables have been developed for pinyon and juniper species in New Mexico and Arizona by Howell (1937, 1940) and by Howell and Lexen (1939), in northern New Mexico and south-central Colorado by Estola (1979), and in northern New Mexico by Clendenen (1979). Moessner (1962) developed an aerial volume table for pinyon and juniper in Utah. Reveal (1944) reported volume characteristics of singleleaf pinyon and Utah juniper in western Nevada.

A comprehensive study of biomass characteristics of singleleaf pinyon *(Pinus monophylla)* and Utah juniper *(Juniperus osteosperma)* has been completed recently (Budy and others 1979). Some preliminary results of this study were reported in notes on line-intersect sampling (Meeuwig and others 1978) and on aerial sampling (Meeuwig and others 1979). These notes introduced the concept of probability proportional to size (p.p.s.) sampling in pinyon-juniper woodlands. This report elaborates on the concept, explaining in detail how point sampling and line-intersect sampling can be used to determine biomass, growth rates, and other characteristics of singleleaf pinyon-Utah juniper stands.

The angle method, originated by Bitterlich (1947) to estimate stand basal area, was extended to timber cruising by Grosenbaugh (1952). It proved to be an efficient and relatively simple method for forest inventory. Standard procedures are described in forest mensuration texts such as that by Husch and others (1972). The method is not feasible in many pinyon-juniper stands because of irregular stems, multiple stems, and stems concealed by foliage. Juniper trees do not generally appear amenable to angle cruising, but the method can be applied successfully to pinyon trees in many cases if stump height instead of breast height is used as the sighting level.

The point sampling procedure described in this paper uses two different, but related, methods for selecting sample trees. The Bitterlich method is used for pinyons, and a method based on crown area is used for juniper. A juniper tree would be included in the sample if the distance from the sample point to its stem center is no greater than its average crown diameter. Thus, pinyon is sampled in proportion to basal area and juniper is sampled in proportion to crown area.

In stands where the Bitterlich method cannot be applied satisfactorily, line-intersect sampling can be used instead. Line-intersect sampling was conceived by Warren and Olsen (1964) to assess logging waste in New Zealand and Brown (1971) adapted it to sample forest fuels. Vries (1973) presented a generalized theory on line-intersect sampling. Meeuwig and others (1978) developed a pinyon-juniper cordwood cruising method using line-intersect sampling. The method is simple; trees are included in the sample if any portion of their crown intersects a transect line. This method samples in proportion to crown diameter and, therefore, is less efficient than point sampling, but it is usually easier to use in pinyon-juniper woodlands.

Two different proportional sampling methods have been described: point and line intersect. Which method to use depends primarily on the characteristics of the stand to be sampled. If the stand contains a high proportion of juniper or if the pinyon stems are irregular or difficult to see at stump height, the line-intersect method is the proper choice. But it is difficult to use the line-intersect method in some older stands because the tree crowns are sparse and irregular and reach their maximum spread at heights well above the ground. Here, the point method is the clear choice.

The choice is more difficult in situations between these extremes. The point method is generally more efficient because it samples in proportion to basal area or crown area while the line-intersect method samples in proportion to crown diameter. Therefore, the point method should be used whenever practical, even in those situations where some clearing of the lower branches is occasionally needed to provide a satisfactory view of the stem, or where it may sometimes be necessary to tape stem diameter and distance to determine whether a tree should be tallied or not. In extensive stratified surveys, some stands could be sampled by line intersect while others are sampled by the point method.

At first glance, this paper may seem to be a complicated series of equations and tables and contains elements that may be of little interest to most woodland managers at present. But as utilization and management of pinyon-juniper woodlands intensifies, these procedures will become important aids to effective management of the woodlands.

The regression equations are more complex than most published biomass equations or volume equations. This complexity is caused by the wide variation in the growth form of the species involved. Simpler equations could be developed but would be less precise and not apply to the more extreme growth forms. Although some of the terms in the regression equations are complicated, particularly in the growth equations, the input variables are not. For pinyon biomass, the only input variables are stump diameter, height, and average crown diameter. For juniper biomass, the only input variables are average crown diameter, diameter breast height, and number of stems at breast height. The only additional input variable for the growth equations is decadal radial wood growth (the width of the 10 outermost complete annual rings).

POINT SAMPLING

This procedure is designed for predominantly pinyon stands in which the pinyon stems are sufficiently well-formed and visible at stump height to allow the use of an angle gage. Since Utah juniper stems rarely meet these criteria, an alternative point sampling method based on crown area is used to sample the occasional juniper.

A series of sample points is laid out on the area to be inventoried according to some prearranged system, such as a grid of equally spaced points or as randomly located points. The sampling design depends on the nature of the stand being sampled and the preferences of the designer. Methods for determining the number of sample points required for achieving a given level of accuracy are described in appendix A.

At each sampling point, the sample pinyon trees are selected with an angle gage sighted at stump height (15 cm or 6 inches). The stick-gage described by Meeuwig (1977) is recommended for this purpose because it affords a clearer view than a prism and is easily adjusted for inclined line-of-sight. Basal area factors of 10 m^2/ha or 40 ft^2/acre are about right for well-stocked stands. Smaller basal area factors (*Bf*) should be used in more open stands, because it is desirable to obtain at least one sample tree at each sampling point.

On some borderline trees with irregular stems at stump height, it may be necessary to tape the stump diameter (*Ds*) and the horizontal distance (*L*) from the sampling point to the stem center. A tree would be tallied if

$$\frac{L}{Ds} \text{ is no greater than } \frac{50}{\sqrt{Bf}} \text{ in metric units or}$$

$$\text{no greater than } \frac{33}{\sqrt{Bf/10}} \text{ in U.S. units.}$$

With a basal area factor of 10 m^2/ha, a tree would be tallied if L is no greater than $15.8 \cdot Ds$. With a basal area factor of 40 ft^2/acre, a tree would be tallied if L is no greater than $16.5 \cdot Ds$.

A juniper tree would be sampled if the distance from the sampling point to the nearest portion of its crown is no greater than one-half its average crown diameter. This criterion is essentially equivalent to requiring that the stem center be within one crown diameter of the sampling point, but it is easier to apply and overcomes the problems caused by multiple stems. It would be simpler to sample only those junipers whose crowns are over the sampling point, but this would result in the junipers being undersampled in relation to the pinyons. The sampling intensity is increased fourfold by the selection criterion given above and brought to a level comparable to that of pinyon selected by a 10 m^2/ha or 40 ft^2/acre angle gage.

Estimates of biomass per unit area, stand basal area, growth rates, and other stand characteristics can be obtained at each sampling point. Estimated pinyon biomass per unit area $(\frac{M}{A})$ at a sampling point is calculated by:

$$\frac{M}{A} = Bf \sum^{n} \frac{M_i}{B_i}$$

In metric units, $\frac{M}{A}$ is in kg/ha, Bf is the basal area factor in m^2/ha, M_i is the mass (kg) of each sample pinyon tree, and B_i is the basal area (m^2) of that sample tree at stump height. In U.S. units, $\frac{M}{A}$ is in pounds per acre, Bf is in square feet per acre, M_i is in pounds, and B_i is in square feet.

Estimated juniper biomass per unit area at a sampling point is calculated by:

$$\frac{M}{A} = \frac{k}{4} \sum^{n} \frac{M_i}{Ca_i}$$

Ca_i is the crown area (m^2 or ft^2) of each sample tree. The factor k is 10 000 m^2/ha or 43,560 ft^2/acre, needed to convert the estimate to a kilogram per hectare or a pounds per acre basis. Division by 4 is necessary because the probability of selection of any particular juniper is equivalent to four times its crown area.

The basic strategy in the use of the two preceding equations is to estimate, by regression equations or tables, the biomass per unit basal area $(\frac{M}{B})_i$ of each sample pinyon and the biomass per unit crown area $(\frac{M}{Ca})_i$ of each sample juniper. The sums of the estimates for each of the two species are used in the two equations to obtain estimated biomass per unit land area at each sampling point.

Using the data of the 72 singleleaf pinyons and 33 Utah junipers from the biomass study reported by Budy and others (1979), multiple regression equations were developed for estimating the ratios of mass to basal area $(\frac{M}{B})$ of pinyon and of mass to crown area $(\frac{M}{Ca})$ of juniper for the following tree components:

1. Cordwood: ovendry mass of wood (with bark) larger than 76-mm (3-inch) diameter outside bark.

2. Slash: ovendry mass of all material smaller than 76-mm (3-inch) diameter outside bark.

3. Aboveground biomass: cordwood and slash.

4. Foliage: ovendry mass of needles or scales.

5. Fine fuels: ovendry mass of foliage plus twigs smaller than 6-mm (¼-inch) diameter outside bark.

The equations were developed through the use of a regression screen program designed to minimize the standard deviation from regression (SDR) with as few variables as practical. The pinyon equations are presented in metric units in table 1 and in U.S. units in table 2. The juniper equations are presented in table 3 (metric) and table 4 (U.S.). The coefficient of variation from regression (CVR%) is the standard deviation from regression expressed as a percentage of the mean (Draper and Smith 1960).

Stem diameter of pinyon is measured at 15 cm (6 inches) above average ground level because it is usually easier to measure there and because it is a better predictor of biomass than diameter at breast height or at ground level. Forking of the main stem, which complicates diameter measurements, generally occurs above 15 cm.

Table 1.--*Regression equations for estimating mass per square meter of basal area of pinyon trees. The dependent variable (Y) is component mass divided by basal area (kg/m²). Ds is stem diameter (cm) outside bark at stump height (15 cm).* H *is tree height (m) and* C *is average crown diameter (m)*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *kg/m²* - -		*Percent*	
Total	$\hat{Y} = 310.5H + 616.7C - 75.87Ds - 11511\frac{1}{Ds} + 1099$	3 123	438	14.0	0.846
Cordwood	$\hat{Y} = 266.3H + 89.7C - 836$	1 337	250	18.7	.907
Slash	$\hat{Y} = 16201\frac{C}{Ds} - 29929\frac{1}{Ds} - 17.01Ds + 1064$	1 786	358	20.0	.668
Fine fuels	$\hat{Y} = 10235\frac{C}{Ds} - 46971\frac{C}{Ds^2} - 6.98Ds - 169$	871	233	26.8	.538
Foliage	$\hat{Y} = 4416\frac{C}{Ds} - 172$	506	161	31.9	.402

Table 2.--*Regression equations for estimating weight per square foot of basal area of pinyon trees. The dependent variable (Y) is component weight divided by basal area (lb/ft²). D is stem diameter (inches) outside bark at stump height (6 inches).* H *is tree height in feet and* C *is average crown diameter in feet*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *Lb/ft²* - -		*Percent*	
Total	$\hat{Y} = 19.38H + 38.50C - 39.47Ds - 928.2\frac{1}{Ds} + 225.1$	640	90	14.0	0.846
Cordwood	$\hat{Y} = 16.62H + 5.60C - 171.2$	274	51	18.7	.907
Slash	$\hat{Y} = 398.3\frac{C}{Ds} - 2413\frac{1}{Ds} - 8.85Ds + 217.9$	366	73	20.0	.668
Fine fuels	$\hat{Y} = 251.5\frac{C}{Ds} - 454.5\frac{C}{Ds^2} - 3.63Ds - 34.6$	178	48	26.8	.538
Foliage	$\hat{Y} = 108.5\frac{C}{Ds} - 35.2$	104	33	31.9	.402

Table 3.--*Regression equations for estimating mass per square meter of crown area of juniper trees. The dependent variable (Y) is component mass divided by crown area (kg/m^2).* Db *is stem diameter (cm) outside bark at breast height (137 cm).* C *is average crown diameter in meters and* Sb *is the number of stems larger than 7.6-cm diameter at breast height*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *kg/m^2* - -		*Percent*	
Total	$\hat{Y} = 1.662\frac{Db}{C} + 1.900C - 0.1339C^2 - 3.338$	9.32	1.94	20.9	0.669
Cordwood	$\hat{Y} = 0.6788\frac{Db}{C} + 0.002054Db^2 + 2.355Sb^{-\frac{1}{2}} - 3.195$	2.87	0.60	20.7	.893
Slash	$\hat{Y} = 0.7771\frac{Db}{C} + 1.925C - 0.1800C^2 - 1.393$	6.46	1.54	23.9	.436
Fine fuels	$\hat{Y} = 0.4573\frac{Db}{C} + 0.5734C - 0.0706C^2 + 0.480$	3.48	0.82	23.5	.387
Foliage	$\hat{Y} = 0.3682\frac{Db}{C} + 0.4280C - 0.0544C^2 + 0.443$	2.76	.64	23.2	.397

Table 4.--*Regression equations for estimating weight per square foot of crown area of juniper trees. The dependent variable (Y) is component weight divided by crown area (lb/ft^2).* Db *is stem diameter (inches) outside bark at breast height (4.5 ft).* C *is average crown diameter in feet and* Sb *is the number of stems larger than 3 inches diameter at breast height*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *Lb/ft^2* - -		*Percent*	
Total	$\hat{Y} = 2.836\frac{Db}{C} + 0.1186C - 0.002548C^2 - 0.684$	1.909	0.397	20.9	0.669
Cordwood	$\hat{Y} = 1.158\frac{Db}{C} + 0.002714Db^2 + 0.4823Sb^{-\frac{1}{2}} - 0.654$	0.587	.122	20.7	.893
Slash	$\hat{Y} = 1.326\frac{Db}{C} + 0.1202C - 0.003425C^2 - 0.285$	1.322	.316	23.9	.436
Fine Fuels	$\hat{Y} = 0.780\frac{Db}{C} + 0.0358C - 0.001343C^2 + 0.0983$	.712	.168	23.5	.387
Foliage	$\hat{Y} = 0.628\frac{Db}{C} + 0.0267C - 0.001035C^2 + 0.0907$	.566	.131	23.2	.397

Stem diameter of Utah juniper is often difficult to measure at any height. Main stem forking is common, especially near ground level. On Utah juniper, diameter at breast height (1.37 m or 4.5 ft) is easier to measure and is a better predictor of biomass than diameter at stump height or ground level.

It is necessary on multistem trees to measure all stems larger than 76-mm (3-inch) diameter and calculate an equivalent diameter. Equivalent diameter is the diameter of a circle having the same area as the combined cross-sectional area of the stems of the multistemmed tree. It is the square root of the sum of the squared diameters of the individual stems:

$$\text{Equivalent diameter} = \sqrt{D_1^2 + D_2^2 + \ldots D^2 n} .$$

For pinyon trees that are forked at stump height, equivalent diameter is calculated not only for use with the regression equations and tables but also may be needed to determine whether or not borderline trees should be tallied. Line-intersect sampling should be used instead of the point method if the stand has an appreciable proportion of pinyons that fork at stump height.

Average crown diameter (C) is the geometric mean of the maximum crown diameter (Cx) and the crown diameter (Cy) perpendicular to the axis of the maximum crown diameter.

$$C = \sqrt{Cx \cdot Cy}$$

Crown area (Ca) is calculated by:

$$Ca = \frac{\pi}{4} \cdot Cx \cdot Cy = \frac{\pi}{4} C^2$$

The use of the regression equations is demonstrated in the following sections. The examples are given in U.S. units, but the general procedures would be the same in metric units. In fact, the calculations are often simplified using metric units.

Cordwood and Slash

Table 5 is similar to a volume table, providing estimates of pounds of pinyon cordwood per square foot of stump basal area for various tree heights and crown diameters. It was calculated from the cordwood equation in table 2. Table 6, based on the slash equation in table 2, provides estimates of pinyon slash for various stump diameters and crown diameters.

Estimates of juniper cordwood and slash (in pounds per square foot of crown area) for various crown diameters and stem diameters breast height are in tables 7 and 8. These tables are based on equations in table 4. The estimates in table 7 are for single stem junipers. For multiple stem junipers, count the number of stems 3 inches or more in diameter at breast height and reduce the estimate from table 7 as follows:

No. stems	Subtract
2	0.14 lb/ft^2
3	.20
4	.24
5	.27
6	.29
7	.30
8	.31
9	.32
10	.33
11	.34
12	.34

Table 5.--*Pinyon cordwood in pounds per square foot of stump basal area*

Height	Crown diameter (feet) 8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
Feet							*Pounds per square foot*								
12	73	84	95	107	118	129	140								
13	90	101	112	123	134	146	157								
14	106	117	129	140	151	162	173	185							
15	123	134	145	156	168	179	190	201							
16	140	151	162	173	184	196	207	218	229						
17	156	167	179	190	201	212	223	235	246						
18	173	184	195	206	218	229	240	251	262	274					
19	189	201	212	223	234	245	257	268	279	290					
20	206	217	228	240	251	262	273	284	296	307	318				
21	223	234	245	256	267	279	290	301	312	323	335				
22	239	250	262	273	284	295	306	318	329	340	351	362			
23	256	267	278	289	301	312	323	334	345	357	368	379			
24	272	284	295	306	317	328	340	351	362	373	384	396	407		
25	289	300	312	323	334	345	356	367	379	390	401	412	423		
26	306	317	328	339	351	362	373	384	395	407	418	429	440	451	463
27	322	334	345	356	367	378	390	401	412	423	434	446	457	468	479
28	339	350	361	373	384	395	406	417	429	440	451	462	473	485	496
29		367	378	389	400	412	423	434	445	456	468	479	490	501	512
30		383	395	406	417	428	439	451	462	473	484	495	507	518	529
31			411	422	434	445	456	467	478	490	501	512	523	534	546
32			428	439	450	461	473	484	495	506	517	529	540	551	562
33				456	467	478	489	500	512	523	534	545	556	568	579
34				472	483	495	506	517	528	539	551	562	573	584	595
35					500	511	522	534	545	556	567	578	590	601	612
36					517	528	539	550	562	573	584	595	606	618	629
37						545	556	567	578	589	601	612	623	634	645
38						561	572	584	595	606	617	628	640	651	662
39						578	589	600	611	623	634	645	656	667	679
40						594	606	617	628	639	650	662	673	684	695

Table 6.--*Pinyon slash in pounds per square foot of stump basal area*

Stump diameter	Crown diameter (feet) 8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
Inches							*Pounds per square foot*								
6	294	426	559	692	825	957									
7	266	380	494	608	722	835									
8	244	343	443	542	642	742	841								
9	224	313	401	490	578	667	755								
10	207	286	366	446	525	605	685	764							
11	191	263	336	408	480	553	625	698							
12	176	243	309	375	442	508	574	641	707						
13	162	224	285	346	407	469	530	591	652						
14	149	206	263	320	377	434	491	547	604	661					
15	137	190	243	296	349	402	455	508	562	615					
16	125	174	224	274	324	374	425	475	525	575	622				
17	115	160	207	254	300	347	394	441	488	535	581				
18	102	146	190	234	279	323	367	411	456	500	544	588			
19	91	132	174	216	258	300	342	384	426	468	510	552			
20		119	159	199	239	279	319	358	398	438	478	518	557		
21		107	145	183	221	259	296	334	372	410	448	486	524		
22			131	167	203	239	276	312	348	384	420	457	493	529	565
23			117	152	187	221	256	290	325	360	394	429	464	498	533
24				137	171	204	237	270	303	336	370	403	436	469	502
25				123	155	187	219	251	283	314	346	378	410	442	474
26					140	171	201	232	263	293	324	355	385	416	446
27					126	155	185	214	244	273	303	332	362	391	421
28						140	168	197	225	254	282	311	339	368	396
29						125	153	180	208	235	263	290	318	345	372
30							138	164	191	217	244	270	297	323	350
31							123	148	174	200	225	251	277	303	328
32								133	158	183	208	233	258	282	307
33								118	142	167	191	215	239	263	287
34									127	151	174	197	221	244	268
35									112	135	158	181	203	226	249
36										120	142	164	186	208	231

Table 7.--*Juniper cordwood in pounds per square foot of tree crown area*

D.b.h.	Crown diameter (feet)												
	8	10	12	14	16	18	20	22	24	26	28	30	32
Inches	- - - - - - - - - - - - - - - - - - *Pounds per square foot* - - - - - - - - - - - - - - - - - -												
4	0.45	0.33	0.26	0.20	0.16								
5	.62	.48	.38	.31	.26	0.22							
6	.79	.62	.50	.42	.36	.31	0.27						
7	.97	.77	.64	.54	.47	.41	.37						
8	1.16	.93	.77	.66	.58	.52	.47	0.42					
9	1.35	1.09	.92	.79	.70	.63	.57	.52	0.48				
10	1.55	1.26	1.06	.93	.82	.74	.68	.63	.58	0.54			
11	1.75	1.43	1.22	1.07	.95	.86	.79	.74	.69	.65			
12	1.96	1.61	1.38	1.21	1.09	.99	.91	.85	.80	.75	0.72		
13		1.79	1.54	1.36	1.23	1.12	1.04	.97	.91	.87	.82		
14		1.98	1.71	1.52	1.37	1.26	1.17	1.10	1.04	.98	.94	0.90	
15			1.89	1.68	1.52	1.40	1.31	1.23	1.16	1.11	1.06	1.02	
16			2.07	1.85	1.68	1.55	1.45	1.37	1.30	1.24	1.18	1.14	1.10
17				2.02	1.84	1.71	1.60	1.51	1.43	1.37	1.32	1.27	1.23
18				2.20	2.01	1.87	1.75	1.66	1.58	1.51	1.45	1.40	1.36
19					2.18	2.03	1.91	1.81	1.72	1.65	1.59	1.54	1.50
20					2.36	2.20	2.07	1.97	1.88	1.80	1.74	1.69	1.64
21						2.38	2.24	2.13	2.04	1.96	1.89	1.84	1.79
22						2.56	2.42	2.30	2.20	2.12	2.05	1.99	1.94
23							2.60	2.47	2.37	2.29	2.22	2.15	2.10
24							2.78	2.66	2.55	2.46	2.38	2.32	2.26

Table 8.--*Juniper slash in pounds per square of tree crown area*

D.b.h.	Crown diameter (feet)												
	8	10	12	14	16	18	20	22	24	26	28	30	32
Inches	- - - - - - - - - - - - - - - - - - *Pounds per square foot* - - - - - - - - - - - - - - - - - -												
4	1.12	1.10	1.11	1.09									
5	1.29	1.24	1.22	1.20	1.17	1.14							
6	1.45	1.37	1.33	1.29	1.26	1.21							
7	1.62	1.50	1.44	1.39	1.34	1.28	1.21	1.12					
8	1.78	1.63	1.55	1.48	1.42	1.36	1.28	1.18	1.07				
9	1.95	1.77	1.66	1.58	1.51	1.43	1.34	1.24	1.12				
10	2.11	1.90	1.77	1.67	1.59	1.50	1.41	1.30	1.18	1.03			
11	2.28	2.03	1.88	1.77	1.67	1.58	1.48	1.36	1.23	1.08			
12	2.45	2.16	1.99	1.86	1.75	1.65	1.54	1.42	1.29	1.13	0.96		
13		2.30	2.10	1.96	1.84	1.72	1.61	1.48	1.34	1.19	1.01		
14		2.43	2.21	2.05	1.92	1.80	1.68	1.54	1.40	1.24	1.06	0.85	
15			2.32	2.15	2.00	1.87	1.74	1.60	1.45	1.29	1.10	.90	
16			2.43	2.24	2.09	1.95	1.81	1.66	1.51	1.34	1.15	.94	0.71
17				2.34	2.17	2.02	1.87	1.72	1.56	1.39	1.20	.99	.76
18				2.43	2.25	2.09	1.94	1.78	1.62	1.44	1.25	1.03	.80
19					2.33	2.17	2.01	1.84	1.67	1.49	1.29	1.08	.84
20					2.42	2.24	2.07	1.90	1.73	1.54	1.34	1.12	.88
21						2.31	2.14	1.97	1.78	1.59	1.39	1.16	.92
22						2.39	2.21	2.03	1.84	1.64	1.43	1.21	.96
23							2.27	2.09	1.90	1.70	1.48	1.25	1.00
24							2.34	2.15	1.95	1.75	1.53	1.30	1.05

As an example of the use of these tables, let us assume a sampling point where two pinyons are "in" on an angle gage having a basal area factor of 40 ft^2/acre, and one juniper crown is closer than one-half of its average crown diameter to the sampling point. Height, crown diameter, and stump diameter of the two pinyons are:

	Pinyon No. 1	Pinyon No. 2
Height (ft)	20	18
Crown diameter (ft)	14	12
Stump diameter (inches)	12	8

The juniper has an average crown diameter of 12 ft and two stems at breast height 4 inches and 7 inches in diameter.

Estimated pinyon cordwood (table 5) at the sampling point is:

$$Bf \sum^{n} \left(\frac{\hat{W}}{B}\right)_i = 40 \text{ ft}^2/\text{acre} \times (240 \text{ lb/ft}^2 + 195 \text{ lb/ft}^2) = 17{,}400 \text{ lb/acre}$$

The average ovendry weight of a solid cubic foot of pinyon cordwood (with bark) is 29 lb. The estimated pinyon cordwood in cubic feet per acre is:

$$17{,}400 \text{ lb/acre} \div 29 \text{ lb/ft}^3 = 600 \text{ ft}^3/\text{acre}$$

For the sample juniper tree, the equivalent Db is $\sqrt{4^2 + 7^2} = 8$ inches. Table 7 shows 0.77 lb/ft^2 of crown area for a single stem juniper with a Db of 8 inches and an average crown diameter of 12 ft. Since this is a two-stem juniper, the estimate is reduced by 0.14 to 0.63 lb/ft^2. Estimated juniper cordwood is:

$$\frac{k}{4} \sum^{n} \left(\frac{\hat{W}}{Ca}\right)_i = \frac{43{,}540 \text{ ft}^2/\text{acre}}{4} \times 0.63 \text{ lb/ft}^2 = 6{,}861 \text{ lb/acre}$$

The average ovendry weight of a solid cubic foot of juniper cordwood (with bark) is 24 lb. The estimated juniper cordwood in cubic feet per acre is:

$$6{,}861 \text{ lb/acre} \div 24 \text{ lb/ft}^3 = 286 \text{ ft}^3/\text{acre}$$

Total estimated cordwood at the sampling point is 886 ft^3/acre.

Estimated pinyon slash (table 6) is:

$$Bf \sum^{n} \left(\frac{\hat{S}}{B}\right)_i = 40 \text{ ft}^2/\text{acre} \times (375 \text{ lb/ft}^2 + 443 \text{ lb/ft}^2) = 32{,}720 \text{ lb/acre.}$$

Estimated juniper slash (table 8) is:

$$\frac{k}{4} \sum^{n} \left(\frac{\hat{S}}{Ca}\right)_i = \frac{43{,}560 \text{ ft}^2/\text{acre}}{4} \times 1.55 \text{ lb/ft}^2 = 16{,}880 \text{ lb/acre.}$$

Total estimated slash at the sampling point is 49,600 lb/acre, or about 25 tons per acre (ovendry weight).

A survey of a tract would consist of a number of sampling points and the average of the per acre estimates at each point is the estimated pounds (or cubic feet) per acre for the tract. Pinyon cordwood weight (*Wp*) in a tract can be calculated by:

$$Wp = \frac{A \cdot Bf}{N} \sum^{N} \sum^{n} \left(\frac{\hat{W}}{B}\right)_i$$

in which

A	is the tract area (acres)
N	is the number of sampling points
n	is the number of sample pinyons at a sampling point
Bf	is the basal area factor (ft^2/acre)
$\left(\frac{\hat{W}}{B}\right)_i$	is the estimated cordwood weight per square foot basal area of each pinyon (from table 5).

This estimate can be converted to cubic foot volume (*Vp*) by dividing by 29 lb/ft^3. If a *Bf* of 40 ft^2/acre is used:

$$Vp = \frac{1.38 \cdot A}{N} \sum^{N} \sum^{n} \left(\frac{\hat{W}}{B}\right)_i$$

Juniper cordwood weight (*Wj*) in a tract can be calculated by:

$$Wj = \frac{10{,}890 \cdot A}{N} \sum^{N} \sum^{n} \left(\frac{\hat{W}}{Ca}\right)_i$$

in which $\left(\frac{\hat{W}}{Ca}\right)_i$ is the estimated cordwood weight per square foot of crown area of each sample juniper from table 7. This estimate can be converted to cubic foot volume by dividing by 24 lb/ft^3, or calculated more directly by:

$$Vj = \frac{454 \cdot A}{N} \sum^{N} \sum^{n} \left(\frac{\hat{W}}{Ca}\right)_i$$

The cubic foot volumes can be converted to cords, if desired, by dividing by the number of solid cubic feet in a cord. There are roughly 75 solid cubic feet in a cord of pinyon and juniper. But the amount varies with the size, length, and shape of the material, and how carefully it is stacked.

Predicted slash weights in a tract can be calculated in the same manner as cordwood weights using tables 6 and 8.

Aboveground Biomass

Pinyon cordwood per unit basal area can be estimated reliably if average crown diameter and tree height are known. Pinyon slash per unit basal area can be estimated reliably if average crown diameter and stump diameter are known. Reliable estimation of aboveground biomass (cordwood plus slash) per unit basal area requires all three variables: crown diameter, height, and stump diameter (table 2). (Tables with three input variables are cumbersome and are not included in this paper.) Aboveground biomass can be calculated either by using a computer or programable calculator to solve the regression equation or by simply adding estimated slash and estimated cordwood together. The second method is nearly as precise as the first.

Returning to the hypothetical sampling point used as an example in the last section, the estimated total aboveground biomass of pinyon per acre obtained by adding cordwood and slash is:

17,400 lb/acre cordwood + 32,720 lb/acre slash = 50,129 lb/acre.

If we use the "total" equation in table 2, estimated aboveground biomass per square foot of basal area is 601 lb/ft^2 for pinyon No. 1 and 604 lb/ft^2 for pinyon No. 2. This yields an estimate of:

$$Bf \sum^{n} \left(\frac{W}{B}\right)_i = 40 \text{ ft}^2/\text{acre} \times (601 + 604) = 48{,}200 \text{ lb/acre.} \qquad \{\text{pinyon}\}.$$

Height apparently has little predictive value for juniper biomass. Aboveground biomass per square foot of crown area of juniper can be reliably estimated if only crown diameter and stem diameter at breast height are known. Table 9, based on the "total" equation in table 4, provides estimated aboveground biomass in pounds per square foot of crown area of juniper. The juniper at the example sampling point has an estimated 2.26 lb/ft^2, yielding an estimate of:

$$\frac{k}{4} \sum^{n} \left(\frac{M}{Ca}\right)_i = 10{,}890 \times 2.26 = 24{,}611 \text{ lb/acre.} \qquad \{\text{juniper}\}$$

of juniper at the sampling point. Estimated aboveground biomass of pinyon and juniper at the sampling point is 72,811 lb/acre, or about 36 tons per acre.

Table 9.--*Juniper aboveground biomass in pounds per square foot of tree crown area*

D.b.h.	Crown diameter (feet)												
	8	10	12	14	16	18	20	22	24	26	28	30	32
Inches	*Pounds per square foot*												
4	1.52	1.38	1.32	1.29	1.27								
5	1.87	1.67	1.55	1.49	1.45	1.41							
6	2.23	1.95	1.79	1.69	1.62	1.57	1.52						
7	2.58	2.23	2.03	1.89	1.80	1.73	1.66	1.59					
8	2.94	2.52	2.26	2.10	1.98	1.89	1.80	1.72	1.64				
9	3.29	2.80	2.50	2.30	2.16	2.04	1.95	1.85	1.76				
10	3.65	3.08	2.74	2.50	2.33	2.20	2.09	1.98	1.88	1.77			
11	4.00	3.37	2.97	2.71	2.51	2.36	2.23	2.11	1.99	1.88			
12	4.36	3.65	3.21	2.91	2.69	2.52	2.37	2.24	2.11	1.99	1.85		
13		3.93	3.44	3.11	2.87	2.67	2.51	2.37	2.23	2.10	1.96		
14		4.22	3.68	3.31	3.04	2.83	2.65	2.50	2.35	2.20	2.06	1.90	
15			3.92	3.52	3.22	2.99	2.80	2.63	2.47	2.31	2.16	2.00	
16			4.15	3.72	3.40	3.15	2.94	2.75	2.59	2.42	2.26	2.09	1.92
17				3.92	3.57	3.30	3.08	2.88	2.70	2.53	2.36	2.19	2.01
18				4.12	3.75	3.46	3.22	3.01	2.82	2.64	2.46	2.28	2.10
19					3.39	3.62	3.36	3.14	2.94	2.75	2.56	2.38	2.19
20					4.11	3.78	3.50	3.27	3.06	2.86	2.66	2.47	2.27
21						3.93	3.65	3.40	3.18	2.97	2.77	2.57	2.36
22						4.09	3.79	3.53	3.29	3.08	2.87	2.66	2.45
23							3.93	3.66	3.41	3.19	2.97	2.76	2.54
24							4.07	3.79	3.53	3.29	3.07	2.85	2.63

Foliage and Fine Fuels

Point sampling procedures for estimating foliage and fine fuels in a stand are the same as those described for estimating slash. Pinyon foliage and fine fuels per unit basal area can be estimated if crown diameter and stump diameter are known. Juniper foliage and fine fuels per unit crown area can be estimated if crown diameter and diameter breast height are known. Tables of estimated foliage and fine fuels are not presented in this paper. They can be prepared, if needed, from the appropriate equations in tables 1 through 4.

Continuing with the example sampling point, the estimated foliage weights per unit basal area of the two sample pinyons are 91.4 lb/ft^2 and 127.6 lb/ft^2 (from the foliage equation in table 2). Estimated pinyon foliage per acre at the sampling point is:

$$Bf \sum^{n} \left(\frac{W}{B}\right)_i = 40 \text{ ft}^2\text{/acre} \times (91.4 + 127.6) \text{ lb/ft}^2 = 8{,}760 \text{ lb/acre.}$$

According to the foliage equation in table 4, the estimated foliage of the sample juniper is 0.681 lb/ft^2. Estimated juniper foliage per acre is 10,890 x 0.681 = 7,416 lb/acre, bringing the total estimated foliage at the sampling point to 16,176 lb/acre, or about 8 tons per acre.

Estimated weight of fine fuels at the sampling point is 25,284 lb/acre, calculated in the same manner as foliage but using the fine fuels equations in tables 2 and 4.

Canopy Cover

Better ways exist for estimating canopy cover of pinyon-juniper stands than the point sampling procedures in this paper. If one is only interested in measuring cover, the line interception method (Canfield 1941) yields better estimates with less field effort. If an estimate of canopy cover is desired in conjunction with a survey of stand biomass, then the computations in this section provide the estimate without requiring additional field measurements.

Estimated juniper canopy cover is simple to calculate. If only junipers with crowns actually intersecting the sample point were tallied, juniper canopy cover of a stand would be calculated by dividing the number of tallied junipers by the number of sample points and multiplying by 100. Since the point-sampling procedures described in this paper increase the sampling probability of juniper by a factor of four, the estimated juniper canopy cover for a stand is:

$$\text{Juniper cover \%} = \frac{100\%}{4 \cdot N} \sum^{N} n_i$$

where N is the number of sampling points and n_i is the number of juniper trees tallied at each sampling point.

Estimated pinyon canopy cover at a sampling point is calculated by multiplying the sum of the ratios of crown area (Ca) to basal area (B) of each sampled pinyon by the basal area factor (Bf):

$$\text{Pinyon cover \% (point estimate)} = 100\% \times Bf \times \sum^{n} \left(\frac{Ca}{B}\right)_i .$$

After making appropriate substitutions and correcting for dimensions, the metric equation is:

$$\text{Pinyon cover \% (point estimate)} = 100 \times Bf \times \sum^{n} \left(\frac{C}{Ds}\right)_i^2$$

where Bf is the basal area factor in m^2/ha, C is average crown diameter in meters, and Ds is stump diameter in centimeters. In U.S. units the equation is:

$$\text{Pinyon cover \% (point estimate)} = 0.3306 \times Bf \times \sum^{n} \left(\frac{C}{Ds}\right)^2_i$$

where Bf is in ft^2/acre, C is in feet, and Ds is in inches.

The average pinyon cover of a stand is:

$$\text{Pinyon cover \% (stand estimate)} = \frac{100 \cdot Bf}{N} \sum^{N}\sum^{n} \left(\frac{C}{Ds}\right)^2_i \qquad \{\text{metric}\}$$

or

$$\frac{0.3306\ Bf}{N} \sum^{N} \sum^{n} \left(\frac{C}{Ds}\right)^2_i \qquad \{\text{U.S.}\}$$

At the hypothetical sampling point, calculated canopy cover is 25 percent juniper and 48 percent pinyon.

Trees per Unit Area

Tree density (trees per hectare or per acre) can be estimated from the data obtained by point sampling. For pinyon, estimated tree density at a sampling point is calculated by summing the reciprocals of the basal area (B_i) of the sample pinyons and multiplying by the basal area factor (Bf).

$$\text{Pinyon density (point estimate)} = Bf \sum^{n} \frac{1}{B_i} .$$

After substituting $\frac{\pi Ds^2}{4}$ for B and correcting for dimensions, the metric equation is:

$$\text{Pinyon trees per hectare (point estimate)} = 12{,}732 \times Bf \sum^{n} \left(\frac{1}{Ds}\right)^2_i$$

where Bf is the basal area factor in m^2/ha and Ds is stump diameter in centimeters. In U.S. units the equation is:

$$\text{Pinyon trees per acre (point estimate)} = 183 \times Bf \sum^{n} \left(\frac{1}{Ds}\right)^2_i$$

with Bf in ft^2/acre and Ds in inches.

The estimated pinyon density for a stand is:

$$\text{Pinyon trees per hectare (stand estimate)} = \frac{12{,}732 \times Bf}{N} \sum^{N} \sum^{n} \left(\frac{1}{Ds}\right)^2_i$$

or

$$\text{Pinyon trees per acre (stand estimate)} = \frac{183 \times Bf}{N} \sum^{N} \sum^{n} \left(\frac{1}{Ds}\right)^2_i$$

where N is the number of sampling points and n is the number of sample pinyons at each point.

Estimated juniper tree density at a sampling point is proportional to the sum of the reciprocals of the crown areas of the sample junipers.

$$\text{Juniper density (point estimate)} = \frac{k}{4} \sum^{n} \frac{1}{Ca_i} = \frac{k}{\pi} \sum^{n} \left(\frac{1}{C}\right)^2_i$$

Ca_i is the crown area (m^2 or ft^2) of each sample tree, k is 10 000 m^2/ha or 43,560 ft^2/acre, and C is average crown diameter (m or ft). The estimated juniper density for a stand is:

$$\text{Juniper trees per hectare (stand estimate)} = \frac{10{,}000}{\pi} \sum^{N} \sum^{n} \left(\frac{1}{C}\right)^2_i \qquad \{\text{metric}\}$$

or

$$\text{Juniper trees per acre (stand estimate)} = \frac{43{,}560}{\pi} \sum^{N} \sum^{n} \left(\frac{1}{C}\right)^2_i \qquad \{\text{U.S.}\}$$

Calculated tree density at the hypothetical sampling point is 165 pinyon trees per acre and 96 juniper trees per acre.

Stand Basal Area

Estimated stand basal area of pinyon at each sampling point is obtained by multiplying the basal area factor by the number of tallied trees. The stand estimate in either m^2/ha or ft^2/acre is:

$$\text{Stand basal area (pinyon)} = \frac{Bf}{N} \sum^{N} n_i$$

where n_i is the number of tallied pinyon trees at each sampling point. Since stump height (15 cm or 6 inches) is used as the target level for the angle gage, the estimated basal area is also at stump height rather than at conventional breast height.

Estimated stand basal area of juniper at a sampling point is proportional to the sum of the ratios of basal area to crown area of the sample juniper trees.

$$\text{Stand basal area (juniper)} = \frac{k}{4} \sum^{n} \left(\frac{B}{Ca}\right)_i$$

where B is tree basal area (m^2 or ft^2), Ca is crown area (m^2 or ft^2), and k is 10 000 m^2/ha or 43,560 ft^2/acre.

For consistency, it is desirable to express juniper basal area at the same height as pinyon. To eliminate the need for diameter measurements at stump height, which are often difficult on junipers, regression equations have been developed to estimate the ratio of stump basal area to crown area:

$$\widehat{\left(\frac{k \cdot B}{Ca}\right)} = 32.467 - 0.4705\ Db + 1.221\ \left(\frac{Db}{C}\right)^2 \qquad \{\text{metric}\}$$

$$\widehat{\left(\frac{k \cdot B}{Ca}\right)} = 141.4 - 5.21\ Db + 369.4\ \left(\frac{Db}{C}\right)^2 \qquad \{\text{U.S.}\}$$

in which $\left(\frac{k \cdot B}{Ca}\right)$ is estimated basal area at stump height divided by crown area (m^2/ha or ft^2/acre), *Db* is diameter breast height (cm or inches), and *C* is average crown diameter (m or ft). These equations are based on the same data as the preceding biomass equations. The R^2 is 0.472 and CVR is 23.8 percent for these equations.

Ratios of juniper stump basal area to crown diameter (in square feet per acre) at various crown diameters and breast height diameters are listed in table 10. The sample juniper at the example sampling point, with an average crown diameter of 12 ft and an equivalent *Db* of 8 inches, has a basal area to crown ratio of 264 ft^2/acre. The estimated stand basal area of juniper at the sampling point is:

$$\frac{1}{4} \sum^{n} \left(\frac{k \cdot B}{Ca}\right)_i = \frac{264}{4} = 66\ ft^2/\text{acre}.$$

Total estimated stand basal area at the sampling point is 146 ft^2/acre (80 + 66).

Table 10.--*Ratios of juniper stump basal area to tree crown area*

	Crown diameter (feet)												
D.b.h.	8	10	12	14	16	18	20	22	24	26	28	30	32
Inches	- - - - - - - - - - - - - - - - - - - *Square feet per acre* - - - - - - - - - - - - - - - - -												
4	213	180	162	151	144								
5	260	208	179	162	151	144							
6	318	243	202	178	162	151	143						
7	388	286	231	197	176	161	150	142					
8	469	336	264	220	192	173	159	149	141				
9	562	394	302	247	211	187	169	156	146				
10	666	459	346	278	234	203	182	166	153	144			
11	782	531	394	312	259	222	196	176	162	150			
12	910	611	448	350	287	243	212	189	171	158	147		
13		698	507	392	318	266	230	203	182	166	153		
14		792	571	438	351	292	249	218	194	176	161	149	
15			640	487	388	320	271	235	208	186	169	156	
16			715	541	427	350	294	253	222	198	179	163	150
17				598	470	383	320	273	238	211	189	171	157
18				658	515	417	347	295	255	225	200	181	165
19					563	454	376	318	274	240	213	191	173
20					614	493	407	342	294	256	226	201	181
21						535	439	369	315	273	240	213	191
22						579	474	396	337	291	255	225	201
23							510	425	361	311	271	239	212
24							548	456	386	331	288	253	224

Growth Rates

Procedures for point sampling decadal growth rates in terms of stand basal area, total aboveground biomass, and cordwood are described in this section. Growth rate estimates require measurement of radial growth in addition to the measurements for biomass estimates. Measurements of decadal radial growth can be made on cores obtained with an increment hammer at stump height on pinyon and at breast height on juniper. It is usually difficult to obtain usable cores from juniper with an increment borer, but an increment hammer works well if the bit is kept sharp.

Growth rates during the 10 years prior to sampling were calculated for the 72 pinyons and 33 junipers, using the stem analysis procedures described by Meeuwig and Budy (1979) and by Meeuwig (1979). The regression equations in table 11 were developed by the same screen regression procedures that were used for the biomass equations in this paper, and are applied in the same manner. The equations provide estimates of decadal growth rates of tree basal area, cordwood, and total aboveground biomass of singleleaf pinyon and Utah juniper in both metric and U.S. units. Except for pinyon basal area growth and juniper total growth, the equations require at least three input variables and are not easily presentable in tabular form.

Pinyon basal area growth per unit basal area is, of course, closely correlated with the ratio of radial wood growth to diameter outside bark. Slight variation in the bark thickness/diameter ratios is the main reason for lack of perfect correlation. Table 12 gives basal area growth/basal area ratios over a range of radial growth/diameter ratios. Since both ratios are dimensionless except for time, the table is applicable in both metric and U.S. units.

Continuing with the example from the preceding sections, let us assume that the average combined width of the last 10 complete annual rings in cores from the 12-inch diameter pinyon is 0.5 inches and that of the 8-inch diameter pinyon is 0.4 inches. The radial growth/diameter ratios (X) are 0.042 and 0.050, respectively. The estimated basal area growth/basal area ratios (from the pinyon basal area growth equation in table 11, or interpolated from table 12) are 0.19 and 0.22 ft^2/decade/ft^2. Estimated pinyon stand basal area growth at the sampling point is:

$$Bf \sum^{n} \left(\frac{\hat{\Delta B}}{B}\right)_i = 40 \text{ ft}^2\text{/acre x } (0.19 + 0.22)\text{/decade} = 16.4 \text{ ft}^2\text{/acre/decade.}$$

No tables are presented in this paper for the other growth equations. They can be used more efficiently with computers or programable calculators than with tables. From the appropriate equations in table 11, estimated pinyon cordwood growth and aboveground biomass growth at the hypothetical sampling point are:

Pinyon cordwood growth = 40 ft^2/acre x (69 + 66) lb/ft^2/decade = 5,400 lb/acre/decade

Pinyon aboveground growth = 40 ft^2/acre x (137 + 167) lb/ft^2/decade = 12,160 lb/acre/decade.

For pinyons with more than one stem at stump height, the cores are taken from the largest stem, and then the average combined width of the 10 rings is divided by the diameter (outside bark) of that stem to determine the radial growth/diameter growth ratio. Equivalent radial growth is calculated by multiplying this ratio by the equivalent diameter. This simplified procedure gives essentially the same results as analyzing the growth of all stems.

For juniper with more than one stem at breast height, the equivalent radial growth (Rb) is determined in the same manner:

$$Rb = \frac{Rb_1}{Db_1} \text{ x } \sqrt{Db_1{}^2 + Db_2{}^2 + ..Db_n{}^2}$$

This sample juniper has two stems with diameters of 7 and 4 inches. If cores taken at breast height on the 7-inch stem show an average radial wood growth of 0.35 inches in 10 years, then

$$Rb = \frac{0.35}{7} \text{ x } \sqrt{7^2 + 4^2} = 0.40 \text{ inches}$$

Table 11.--*Regression equations for estimating basal area, aboveground biomass, and cordwood growth rates of pinyon and juniper trees. The dependent variable (Y) is decadal growth divided by basal area for pinyon, or decadal growth divided by crown area for juniper. Independent variables are defined at the bottom of the table*

Equations	$\bar{Y}$	SDR	CVR	R^2
			Percent	
Metric				
Pinyon basal area growth/basal area	(cm^2/decade/m^2)			
$\hat{Y} = 48910X - 66590X^2 - 36$	2298	146	6.3	0.991
Pinyon total aboveground biomass growth/basal area	(kg/decade/m^2)			
$\hat{Y} = 1408X \cdot H + 4055X \cdot C - 423.6Rs + 120$	802	154	19.2	.877
Pinyon cordwood growth/basal area	(kg/decade/m^2)			
$\hat{Y} = 947X \cdot H - 3098X^2 \cdot H + 25.8Rs\ H - 128Rs + 91$	353	66	18.8	.822
Juniper basal area growth/crown area	(cm^2/decade/m^2)			
$\hat{Y} = 55.68\frac{Rb}{C} - 2.261\frac{Rb^2}{C} + 0.2205Db \cdot Rb - 8.06Rb - 0.706$	11.54	1.70	14.8	.972
Juniper total aboveground biomass growth/crown area	(kg/decade/m^2)			
$\hat{Y} = 3.285Rb - 0.3332Rb \cdot C + 0.267$	2.622	0.511	19.5	.919
Juniper cordwood growth/crown area	(kg/decade/m^2)			
$\hat{Y} = 0.1499\frac{Db \cdot Rb}{C} + 13.51\frac{Rb^2}{C \cdot Db} - 4.466\frac{Rb \cdot Sb^{\frac{1}{2}}}{Db} + 0.083$	0.810	0.167	20.6	.904
U.S.				
Pinyon basal area growth/basal area	(ft^2/decade/ft^2)			
$\hat{Y} = 4.89X - 6.66X^2 - 0.0036$	0.2300	0.0146	6.3	.991
Pinyon total aboveground biomass growth/basal area	(lb/decade/ft^2)			
$\hat{Y} = 87.89X \cdot H + 253.13X \cdot C - 220.35Rs + 24.6$	164.2	31.5	19.2	.877
Pinyon cordwood growth/basal area	(lb/decade/ft^2)			
$\hat{Y} = 59.12X \cdot H - 193.4X^2 \cdot H + 4.09Rs \cdot H - 66.6Rs + 18.6$	72.2	13.5	18.8	.822
Juniper basal area growth/crown area	(ft^2/decade/acre)			
$\hat{Y} = 2021\frac{Rb}{C} - 208.7\frac{Rb^2}{C} + 6.197Db \cdot Rb - 89.2Rb - 3.08$	50.27	7.41	14.8	.972
Juniper total aboveground biomass growth/crown area	(lb/decade/ft^2)			
$\hat{Y} = 1.709Rb - 0.0528Rb \cdot C + 0.055$	0.537	0.105	19.5	.919
Juniper cordwood growth/crown area	(lb/decade/ft^2)			
$\hat{Y} = 0.650\frac{Db \cdot Rb}{C} + 9.08\frac{Rb}{C \cdot Db} - 0.915\frac{Rb \cdot Sb^{\frac{1}{2}}}{Db} + 0.017$	0.166	0.034	20.6	.904

Definition of Symbols

H = tree height (meters or feet)
C = average crown diameter (meters or feet)
Ds = diameter outside bark at stump height (centimeters or inches)
Rs = radial wood growth at stump height in the last 10 years (centimeters per decade or inches per decade)
X = Rs/Ds (dimensionless)
Db = diameter outside bark at breast height (centimeters or inches)
Rb = radial wood growth at breast height in the last 10 years (centimeters per decade or inches per decade)
Sb = number of stems larger than 76 mm (3 inches) at breast height

Table 12.--*Ratio of decadal basal area growth* (ΔB) *to tree basal area* (B) *as a function of the ratio of decadal radial wood growth* (Rs) *to stump diameter* (Ds) *of pinyon. The ratios are dimensionless*

Rs/Ds	$\Delta B/B$
0.01	0.04
.02	.09
.03	.13
.04	.18
.05	.22
.06	.26
.07	.30
.08	.34
.09	.38
.10	.41
.11	.45
.12	.48
.13	.52
.14	.55
.15	.58
.16	.60
.17	.63
.18	.66
.19	.69
.20	.71

From the last three equations in table 11, estimated growth at the sampling point is:

$$\text{Juniper basal area growth} = \frac{45.65\ \text{ft}^2/\text{decade/acre}}{4} = 11.4\ \text{ft}^2/\text{acre/decade}$$

$$\text{Juniper total growth} = \frac{43{,}560\ \text{ft}^2/\text{acre}}{4} \times 0.485\ \text{lb/decade/ft}^2 = 5{,}282\ \text{lb/acre/decade}$$

$$\text{Juniper cordwood growth} = \frac{43{,}560\ \text{ft}^2/\text{acre}}{4} \times 0.163\ \text{lb/decade/ft}^2 = 1{,}775\ \text{lb/acre/decade}$$

Juniper increment cores are taken at breast height because it is easier to obtain representative cores there, but basal area growth is estimated at stump height to be consistent with the pinyon estimates. No conversion from square feet to acres is needed in the juniper basal area growth calculation because the regression estimate is in square feet per decade per acre of crown area.

Estimated decadal growth of pinyon and juniper combined at the sampling point is:

Basal area: 28 ft^2/acre/decade

Total aboveground biomass: 8.7 tons/acre/decade

Cordwood: 3.6 tons/acre/decade or 260 ft^3/acre/decade

Estimates of stand growth are calculated in the same manner as estimates of stand biomass. The generalized equations are:

$$\text{Pinyon decadal growth (stand estimate)} = \frac{A \cdot Bf}{N} \sum^{N} \sum^{n} \hat{y}_i$$

$$\text{Juniper decadal growth (stand estimate)} = \frac{A \cdot k}{4N} \sum^{N} \sum^{n} \hat{y}_i$$

in which A = stand area in hectares or acres, Bf is the basal area factor in m^2/ha or ft^2/acre, N is the number of sampling points, n is the number of sample trees at each sampling point, $\hat{y}_i$ is the regression estimates of the ratio of decadal growth to basal area (pinyon) or to crown area (juniper), and k is 10 000 m^2/ha or 43,560 ft^2/acre.

LINE-INTERSECT SAMPLING

The procedures in this section are modifications and elaborations of the cordwood sampling procedure described by Meeuwig and others (1978). A number of transect lines are laid out, preferably with staff compass and tape, in some predetermined design. Except as noted below, trees are tallied if any portion of their crown is over a transect line. A tree would not be tallied if the center of its root crown lies beyond either end of a transect. If transects are laid out in a continuous series of line segments, this exception applies only to the two ends of the series. Within the series, a borderline tree may be tallied in either transect that its crown intersects, but not both.

The length of the transect can vary, depending on stand conditions. For most well-stocked stands, 30 m or 100 ft is about right. In dense stands, 20 m or 66 ft may be more convenient. In more open stands, it may be desirable to use 40 m or 132 ft. For statistical reasons, it is desirable to have at least two sample trees in each transect.

Estimates of biomass per unit land area, stand basal area, growth rates, and other stand characteristics can be calculated for each transect. Estimated biomass per unit area for a transect is:

$$\frac{M}{A} = \frac{k}{L} \sum^{n} \widehat{\left(\frac{M}{C}\right)}_i$$

In metric units, $\frac{M}{A}$ is estimated biomass in kg/ha, k is 10 000 m^2/ha, L is transect length in meters, n is the number of sample trees in the transect, and $\widehat{(\frac{M}{C})}_i$ is the ratio of biomass to average crown diameter (kg/m) as estimated by regression. In U.S. units, $\frac{M}{A}$ is pounds per acre, k is 43,560 ft^2/acre, L is feet, and $\widehat{(\frac{M}{C})}_i$ is pounds per foot.

Estimated biomass for a stand or tract is:

$$\text{Biomass (stand estimate)} = \frac{A \cdot k}{N \cdot L} \sum^{N} \sum^{n} \widehat{\left(\frac{M}{C}\right)}_i$$

in which A is area of the stand in hectares or acres and N is the number of transects.

Regression equations for estimating the ratios of biomass components to average crown diameters are presented in metric units in table 13 and in U.S. units in table 14. These equations were developed in essentially the same manner as the point-sampling equations and use the same set of input variables.

Line-intersect procedures for estimating the various biomass components, canopy cover, tree density, stand basal area, and growth rates are described in the following sections. A hypothetical transect is used throughout as an example to illustrate the procedures. This transect is 100 ft long and intersects five trees:

	Tree number				
	1	2	3	4	5
Species	P	P	P	J	J
Crown diameter (ft)	10	14	12	16	18
Height (ft)	16	20	18	--	--
Diameter, stump (inches)	6	12	8	--	--
Diameter b.h. (inches)	--	--	--	10	6 & 7
Equivalent diameter (inches)	--	--	--	--	9
Radial wood growth (inches/decade)	0.35	0.50	0.40	0.40	0.35

No height measurements are required for juniper. Stem diameter is measured at stump height (15 cm or 6 inches) on pinyon and at breast height (137 cm or 4.5 ft) on juniper. Sample tree 5 has two stems at breast height; its equivalent diameter is calculated as described earlier in this paper.

Table 13.--*Regression equations for estimating mass (kg) per meter of crown width of pinyon and juniper trees. The dependent variable* (Y) *is component mass divided by crown width (kg/m).* Ds *is stem diameter (cm) at stump height (15 cm) and* Db *is stem diameter (cm) at breast height (137 cm).* H *is tree height and* C *is average crown diameter, both in meters.* Sb *is the number of stems larger than 7.6 cm diameter at breast height*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *kg/m* - -		*Percent*	
Pinyon					
Total	$\hat{Y} = 0.7228Ds + 0.2269Ds \cdot H - 0.0004256Ds^2 \cdot H - 11.44$	60.97	8.24	13.5	0.976
Cordwood	$\hat{Y} = 0.1734Ds \cdot H - 0.7103Ds + 0.008597Ds^2 + 0.722$	30.70	7.15	23.3	.964
Slash	$\hat{Y} = 1.981Ds - 0.01227Ds^2 - 16.62$	30.27	6.24	20.6	.881
Fine fuels	$\hat{Y} = 0.7468Ds - 0.00503Ds^2 - 3.60$	13.55	3.71	24.4	.761
Foliage	$\hat{Y} = 0.4380Ds - 0.00295Ds^2 - 2.21$	7.85	2.19	27.9	.715
Juniper					
Total	$\hat{Y} = 3.214C + 1.349Db - 6.83$	33.05	6.86	20.7	0.906
Cordwood	$\hat{Y} = -0.7177Db + 0.02157Db^2 - 0.8481\frac{Db}{Sb} + 1.554\frac{Db}{Sb^{\frac{1}{2}}} + 1.71$	11.00	2.14	19.4	.968
Slash	$\hat{Y} = 10.82C + 2.425\frac{Db}{C} - 0.5688C^2 - 22.55$	22.05	4.99	22.6	.834
Fine fuels	$\hat{Y} = 5.582C + 1.334\frac{Db}{C} - 0.3585C^2 - 10.61$	11.42	2.60	22.8	.773
Foliage	$\hat{Y} = 4.343C + 1.136\frac{Db}{C} - 0.2809C^2 - 8.48$	9.06	2.15	23.7	.757

Table 14.--*Regression equations for estimating weight (lb) per foot of crown width of pinyon and juniper trees. The dependent variable is component weight divided by crown width (lb/ft). Ds is stem diameter in inches at stump height (6 inches) and Db is stem diameter at breast height (4.5 feet). H is tree height in feet and C is average crown diameter in feet. Sb is the number of stems larger than 3 inches diameter at breast height*

Component	Regression equation	$\bar{Y}$	SDR	CVR	R^2
		- - *Lb/ft*	- -	*Percent*	
Pinyon					
Total	$\hat{Y} = 1.234Ds + 0.1180Ds \cdot H - 0.000562Ds^2 \cdot H - 7.69$	40.97	5.54	13.5	0.976
Cordwood	$\hat{Y} = 0.0902Ds \cdot H + 0.0373Ds^2 - 1.212Ds + 0.48$	20.63	4.80	23.3	.964
Slash	$\hat{Y} = 3.381Ds - 0.0532Ds^2 - 11.17$	20.34	4.19	20.6	.881
Fine fuels	$\hat{Y} = 1.275Ds - 0.0218Ds^2 - 2.42$	9.11	2.49	24.4	.761
Foliage	$\hat{Y} = 0.748Ds - 0.0128Ds^2 - 1.48$	5.28	1.47	27.9	.715
Juniper					
Total	$\hat{Y} = 0.6583C + 2.303Db - 4.59$	22.21	4.61	20.7	.906
Cordwood	$\hat{Y} = -1.225Db + 0.0935Db^2 - 1.448\frac{Db}{Sb} + 2.652\frac{Db}{Sb^{1/2}} + 1.152$	7.39	1.44	19.4	.968
Slash	$\hat{Y} = 2.216C + 13.58\frac{Db}{C} - 0.0355C^2 - 15.15$	14.82	3.35	22.6	.834
Fine fuels	$\hat{Y} = 1.143C + 7.470\frac{Db}{C} - 0.0224C^2 - 7.13$	7.67	1.75	22.8	.773
Foliage	$\hat{Y} = 0.890C + 6.362\frac{Db}{C} - 0.0175C^2 - 5.70$	6.09	1.44	23.7	.757

Cordwood and Slash

Estimates of pinyon cordwood, pinyon slash, juniper cordwood, and juniper slash (all in pounds per foot of crown diameter) are in tables 15 through 18. These tables are based on the equations in table 14.

From table 15, the cordwood estimates for the three sample pinyons on the example transect are 3, 13, and 6 lb/ft. The pinyon cordwood estimate for the example transect is:

$$\frac{k}{L} \sum^{n} \left(\frac{\hat{W}}{C}\right)_i = \frac{43{,}560 \text{ ft}^2/\text{acre}}{100 \text{ ft}} \times (3 + 13 + 6) \text{lb/ft} = 9{,}583 \text{ lb/acre}$$

If cubic volume is desired, the estimate is divided by 29 lb/ft^3 (the specific weight of pinyon cordwood), converting the estimate to 330 ft^3 per acre.

Table 15.--*Pinyon cordwood in pounds per foot of average crown diameter*

Stump diameter	Height (feet)														
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Inches	- - - - - -						*Pounds per foot*		- - - - - -						
6	1	2	3	4	5	6	8	9	10						
7	1	3	4	5	6	8	9	10	12						
8	2	3	5	6	8	9	10	12	13	15					
9	2	4	6	7	9	10	12	14	15	17					
10	3	5	7	8	10	12	14	16	17	19	21				
11	4	6	8	10	12	13	15	17	19	21	23				
12	4	6	9	11	13	15	17	19	22	24	26	28			
13	5	7	10	12	14	17	19	22	24	26	29	31			
14	6	9	11	14	16	19	21	24	26	29	31	34	36		
15	7	10	12	15	18	20	23	26	29	31	34	37	39		
16	8	11	14	17	20	22	25	28	31	34	37	40	43	45	
17	9	12	15	18	21	24	27	31	34	37	40	43	46	49	
18	10	13	17	20	23	26	30	33	36	39	43	46	49	52	56
19	11	15	18	22	25	29	32	35	39	42	46	49	53	56	59
20	13	16	20	24	27	31	34	38	42	45	49	53	56	60	63
21		18	22	26	29	33	37	41	45	48	52	56	60	63	67
22		20	24	28	32	36	39	43	47	51	55	59	63	67	71
23			26	30	34	38	42	46	50	55	59	63	67	71	75
24			28	32	36	41	45	49	53	58	62	66	71	75	79
25				34	39	43	48	52	57	61	66	70	75	79	84
26				36	41	46	50	55	60	65	69	74	79	83	88
27					44	49	53	58	63	68	73	78	83	87	92
28					46	51	56	61	67	72	77	82	87	92	97
29						54	59	65	70	75	80	86	91	96	101
30						57	63	68	73	79	84	90	95	101	106
31							66	71	77	83	88	94	99	105	111
32							69	75	81	86	92	98	104	110	115
33								79	84	90	96	102	108	114	120
34								82	88	94	101	107	113	119	125
35									92	98	105	111	117	124	130
36									96	103	109	116	122	129	135

From table 16, the cordwood estimates for the two sample junipers are 10 and 8 lb/ft. The second juniper has two stems at breast height, so the second column in the table is used. The estimated juniper cordwood on the sample transect is:

$$\frac{43{,}560 \text{ ft}^2/\text{acre}}{100 \text{ ft}} \times (10 + 8)\text{lb/ft} = 7{,}841 \text{ lb/acre}$$

Dividing this estimate by 24 lb/ft^3 (the specific weight of juniper cordwood) converts the estimate to 327 ft^3/acre. Total estimated cordwood for the example transect is 17,424 lb/acre or 657 ft^3/acre.

From table 17, the slash estimates for the three sample pinyons are 7, 22, and 12 lb/ft. From table 18, the slash estimates for the two junipers are both 20 lb/ft. The estimated slash for the sample transect is:

$$435.6 \text{ ft/acre} \times (7 + 22 + 12 + 20 + 20) \text{ lb/ft} = 35{,}284 \text{ lb/acre}$$

Table 16.--*Juniper wood in pounds per foot of average crown diameter*

D.b.h.	Number of stems											
	1	2	3	4	5	6	7	8	9	10	11	12
Inches												
4	3											
5	3	3										
6	4	4	3									
7	6	5	4	4	3							
8	7	7	6	5	5	4						
9	9	8	7	6	6	5	5	5				
10	10	10	9	8	7	7	6	6	5	5		
11	12	12	11	10	9	8	8	7	7	7	6	
12	14	14	12	11	11	10	9	9	9	8	8	8
13	17	16	15	14	13	12	11	11	10	10	10	9
14	19	18	17	16	15	14	13	13	12	12	12	11
15	22	21	20	18	17	16	16	15	15	14	14	13
16	25	24	22	21	20	19	18	18	17	17	16	16
17	28	27	25	24	23	22	21	20	20	19	19	18
18	31	30	28	27	26	25	24	23	22	22	21	21
19	35	34	32	30	29	28	27	26	25	25	24	24
20	38	37	35	33	32	31	30	29	29	28	27	27
21	42	41	39	37	35	34	33	33	32	31	31	30
22	46	45	43	41	39	38	37	36	35	35	34	34
23	50	49	47	45	43	42	41	40	39	38	38	37
24	55	53	51	49	47	46	45	44	43	42	42	41

Table 17.--*Pinyon slash in pounds per foot of average crown diameter*

Stump diameter	Slash	Stump diameter	Slash
Inches	*Pounds per foot*	*Inches*	*Pounds per foot*
6	7	22	37
7	10	23	38
8	12	24	39
9	15	25	40
10	17	26	41
11	20	27	41
12	22	28	42
13	24	29	42
14	26	30	42
15	28	31	42
16	29	32	43
17	31	33	42
18	32	34	42
19	34	35	42
20	35	36	42
21	36		

Table 18.--*Juniper slash in pounds per foot of average crown diameter*

D.b.h.	Crown diameter (feet) 8	10	12	14	16	18	20	22	24	26	28	30	32
Inches						*Pounds per foot*							
4	7	9	11	13	15	16	18						
5	9	10	12	14	15	17	18						
6	10	12	13	15	16	18	19	20					
7	12	13	14	16	17	19	20	21					
8	14	14	15	17	18	19	20	21	22				
9	16	16	16	18	19	20	21	22	23				
10	17	17	18	19	20	21	22	23	23	24			
11	19	18	19	20	21	22	22	23	24	24			
12	21	20	20	21	21	22	23	24	24	25	25		
13		21	21	22	22	23	24	24	25	25	25		
14		22	22	22	23	24	24	25	25	26	26	26	
15			23	23	24	25	25	26	26	26	26	26	
16			24	24	25	25	26	26	27	27	27	27	26
17				25	26	26	26	27	27	27	27	27	27
18				26	26	27	27	28	28	28	28	28	27
19					27	28	28	28	28	28	28	28	27
20					28	28	29	29	29	29	29	28	28
21						29	29	29	29	29	29	29	28
22						30	30	30	30	30	30	29	29
23							31	31	31	30	30	30	29
24							31	31	31	31	31	30	30

Aboveground Biomass

Estimates of aboveground biomass per foot of crown diameter of pinyon are in table 19. Estimates for juniper are in table 20. These estimates were calculated from the regression equations in table 14.

Continuing with the example, the estimated ratios for the three sample pinyons are 11, 34, and 19 lb/ft. The estimated aboveground biomass of pinyon on the transect is:

$$\frac{k}{L} \sum^{n} \left(\frac{\hat{M}}{C}\right)_i = \frac{43{,}560 \text{ ft}^2\text{/acre}}{100 \text{ ft}} \times (11 + 34 + 19) \text{ lb/ft} = 27{,}878 \text{ lb/acre}$$

The estimated ratios for the two sample junipers are 29 and 28 lb/ft. The estimated aboveground biomass of juniper on the transect is:

$$435.6 \text{ ft/acre} \times (29 + 28) \text{ lb/ft} = 24{,}829 \text{ lb/acre}$$

Estimated aboveground biomass on the transect is 52,707 lb/acre or 26 tons/acre. Aboveground biomass can also be estimated by adding the estimates of cordwood and slash together. The direct estimates are slightly more precise than the summed estimates of cordwood and slash.

Table 19.--*Pinyon aboveground biomass in pounds per foot of average crown diameter*

Stump	Height (feet)														
diameter	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Inches							*Pounds per foot*								
6	8	9	11	12	13	15	16	18	19						
7	11	12	14	15	17	19	20	22	23						
8	13	15	17	19	20	22	24	26	28	29					
9	16	18	20	22	24	26	28	30	32	34					
10	18	20	23	25	27	29	32	34	36	38	41				
11	21	23	26	28	30	33	35	38	40	43	45				
12	23	26	28	31	34	36	39	42	44	47	50	53			
13	26	28	31	34	37	40	43	46	49	52	54	57			
14	28	31	34	37	40	44	47	50	53	56	59	62	65		
15	31	34	37	40	44	47	50	54	57	60	63	67	70		
16	33	36	40	43	47	50	54	61	64	68	71	73	78		
17	33	39	43	46	50	54	58	61	65	69	72	76	80	83	
18	38	42	46	49	53	57	61	65	69	73	77	81	84	88	97
19	40	44	48	52	57	61	65	69	73	77	81	85	89	93	97
20	43	47	51	55	60	64	68	73	77	81	85	90	94	98	102
21		49	54	58	63	67	72	76	81	85	90	94	99	103	107
22		52	57	61	66	71	73	80	85	89	94	98	103	108	112
23			59	64	69	74	79	84	88	93	98	103	108	113	117
24			62	67	72	77	82	87	92	97	102	107	112	117	122
25				70	75	80	86	91	96	101	106	112	117	122	127
26				73	78	84	89	94	100	105	110	116	121	127	132
27					81	87	92	98	103	109	114	120	126	131	137
28					84	90	96	101	107	113	118	124	130	136	141
29						93	99	105	111	117	122	128	134	140	146
30						96	102	108	114	120	126	132	139	145	151
31							105	112	118	124	130	137	143	149	155
32							109	115	121	128	134	141	147	153	160
33								118	125	131	138	145	151	158	164
34								122	128	135	142	149	155	162	169
35									132	139	146	152	159	166	173
36									135	142	149	156	163	170	177

Table 20.--*Juniper aboveground biomass in pounds per foot of average crown diameter*

D.b.h.	Crown diameter (feet)												
	8	10	12	14	16	18	20	22	24	26	28	30	32
Inches	*Pounds per foot*												
4	10	11	13	14	15	16	18						
5	12	14	15	16	17	19	20						
6	14	16	17	18	20	21	22	24					
7	17	18	19	21	22	23	25	26					
8	19	20	22	23	24	26	27	28	30				
9	21	23	24	25	27	28	29	31	32				
10	24	25	26	28	29	30	32	33	34	36			
11	26	27	29	30	31	33	34	35	37	38			
12	28	30	31	32	34	35	36	38	39	40	41		
13		32	33	35	36	37	39	40	41	42	44		
14		34	36	37	38	40	41	42	43	45	46	47	
15			38	39	40	42	43	44	46	47	48	50	
16			40	41	43	44	45	47	48	49	51	52	53
17				44	45	46	48	49	50	52	53	54	56
18				46	47	49	50	51	53	54	55	57	58
19					50	51	52	54	55	56	58	59	60
20					52	53	55	56	57	59	60	61	63
21						56	57	58	60	61	62	64	65
22						58	59	61	62	63	65	66	67
23							62	63	64	65	67	68	69
24							64	65	66	68	69	70	72

Foliage and Fine Fuels

Regression equations for estimating ratios of foliage and fine fuels to crown diameter have the same input variables as the regression equations for slash (tables 13 and 14). Since no tables for foliage and fine fuels are included in this paper, the following estimates were calculated directly from the regression equations in table 14. In actual practice, the user would either prepare the tables or program the equations for evaluation by computer or programable calculator.

The estimated ratios of fine fuels to crown diameter of the three sample pinyons are 4, 10, and 6 lb/ft. For the two sample junipers, the estimates are both 10 lb/ft. The estimated fine fuels at the sample transect are:

$$\frac{k}{L}\sum^{n}\left(\frac{\widehat{FF}}{C}\right)_i = \frac{43{,}560\ \text{ft}^2/\text{acre}}{100\ \text{ft}} \times (4 + 10 + 6 + 10 + 10)\ \text{lb/ft} = 17{,}424\ \text{lb/acre}$$

The estimated ratios of foliage to crown diameter of the three sample pinyons are 3, 6, and 4 lb/ft. The estimates for the two sample junipers are both 8 lb/ft. The estimated foliage at the sample transect is:

$$435.6\ \text{ft/acre} \times (3 + 6 + 4 + 8 + 8) = 12{,}632\ \text{lb/acre}$$

Canopy Cover

The calculation of canopy cover percentage from line-intersect data is simple, but its theoretical basis can be difficult to grasp. The estimate is the sum of the ratios of crown area to crown diameter $(\frac{Ca}{C})_i$ of the intersecting trees divided by the transect length (L) and multiplied by 100 percent:

$$\text{Cover \% (line estimate)} = \frac{100\%}{L} \sum^{n} (\frac{Ca}{C})_i$$

By substituting $\frac{\pi C^2}{4}$ for Ca, the equation is simplified to:

$$\text{Cover \% (line estimate)} = \frac{25\pi}{L} \sum^{n} C_i$$

in which L is transect length in meters or feet and C_i is the average crown diameter of each sampled tree in meters or feet. The estimated canopy cover percentage is directly proportional to the sum of the crown diameters of the sample trees on a transect. Estimated canopy cover at the example transect is:

$$\text{Cover \%} = \frac{25\pi}{100 \text{ ft}} \times (10 + 14 + 12 + 16 + 18) = 55\%$$

Canopy cover by species can be calculated if desired. At the sample transect, the cover percentage is 28 percent pinyon and 27 percent juniper.

The equation for average canopy cover in a stand is:

$$\text{Cover \% (stand estimate)} = \frac{25\pi}{L \cdot N} \sum^{N} \sum^{n} C_i$$

Trees per Unit Area

Estimated tree density is proportional to the sum of the reciprocals of the crown diameters of the sample trees on a transect:

$$\text{Tree density (line estimate)} = \frac{k}{L} \sum^{n} \frac{1}{C_i}$$

On the sample transect, the estimated tree density is:

$$\text{Tree density} = \frac{43{,}560}{100} \times (\frac{1}{10} + \frac{1}{14} + \frac{1}{12} + \frac{1}{16} + \frac{1}{18}) = 162 \text{ trees/acre}$$

Tree density can be calculated by species and even by size classes, if desired.

Stand Basal Area

The generalized equation for calculating stand basal area from line-intersect data is:

$$\text{Stand basal area (line estimate)} = \frac{k}{L} \sum^{n} (\frac{B}{C})_i$$

in which stand basal area is in m^2/ha or ft^2/acre, k is 10 000 m^2/ha or 43,560 ft^2/acre, L is transect length in meters or feet, and $(\frac{B}{C})$ is the ratio of tree basal area (m^2 or ft^2) to average crown diameter (m or ft) of each intersected tree.

After substituting $\frac{\pi Ds^2}{4}$ for B and correcting for dimensional changes, the working equations are:

$$\text{Stand basal area } (m^2/ha) = \frac{\pi}{4L} \sum^{n} (\frac{Ds}{C})_i$$

$$\text{Stand basal area } (ft^2/acre) = \frac{238}{L} \sum^{n} (\frac{Ds^2}{C})_i$$

in which Ds is stump diameter in centimeters or inches and the basal area is at stump height.

Since we have chosen to take basal area at stump height and juniper stem diameter is measured more conveniently and precisely at breast height, we developed regression equations to estimate the ratio of stump basal area to crown diameter of juniper:

$$\widehat{(\frac{B}{C})} = 34.62 + 6.553Db \qquad \{metric\}$$

$$\widehat{(\frac{B}{C})} = 1.636 + 0.7864Db \qquad \{U.S.\}$$

in which $\widehat{(\frac{B}{C})}$ is the ratio of basal area to crown diameter in cm^2/m or $inches^2$/ft and Db is the diameter breast height in centimeters or inches. These equations are based on the same data set as the biomass equations. The R^2 is 0.882 and the CVR is 23.0 percent.

Substituting these equations for $\frac{B}{C}$ in the generalized equation and correcting for dimensions produces these working equations for juniper:

$$\text{Stand basal area } (m^2/ha) = \frac{34.6}{L}n + \frac{6.55}{L} \sum^{n} Db_i$$

$$\text{Stand basal area } (ft^2/acre) = \frac{495}{L}n + \frac{238}{L} \sum^{n} Db_i$$

At the example transect, estimated basal area of pinyon is:

$$\frac{238}{L} \sum^{n} (\frac{Ds^2}{C})_i = \frac{238}{100} \times (\frac{6^2}{10} + \frac{12^2}{14} + \frac{8^2}{12}) = 46 \ ft^2/acre$$

and the estimated basal area of juniper is:

$$\frac{495}{L}n + \frac{238}{L} \sum^{n} Db_i = \frac{495}{100} \times 2 + \frac{238}{100} \times (10 + 9) = 55 \ ft^2/acre$$

Total estimated stand basal area at the transect is 101 ft^2/acre.

Growth Rates

The general equation for calculating estimated stand basal area growth from line intersect data is:

$$\frac{\Delta B}{A} = \frac{k}{L} \sum^{n} \left(\frac{\Delta B}{C}\right)_i$$

$\frac{\Delta B}{A}$ is basal area growth (m /ha/decade or ft /acre/decade) and $\left(\frac{\Delta B}{C}\right)_i$ is the ratio of basal area growth of each sampled tree to its crown diameter (m^2/decade/m or ft^2/decade/ft). The equation simplies to:

$$\frac{\Delta B}{A} = \frac{1}{L} \sum^{n} \left(\frac{\Delta B}{C}\right)_i \qquad \{\text{metric}\}$$

if $\left(\frac{\Delta B}{C}\right)_i$ is expressed in cm^2/decade/m. The U.S. equivalent, if $\left(\frac{\Delta B}{C}\right)_i$ is expressed in $inches^2$/decade/ft, is:

$$\frac{\Delta B}{A} = \frac{302.5}{L} \sum^{n} \left(\frac{\Delta B}{C}\right)_i \qquad \{\text{U.S.}\}$$

The equation for calculating estimated biomass growth is:

$$\frac{\Delta M}{A} = \frac{k}{L} \sum^{n} \left(\frac{\Delta M}{C}\right)_i$$

$\frac{\Delta M}{A}$ is biomass growth (kg/hectare/decade or lb/acre/decade) and $\left(\frac{\Delta M}{C}\right)_i$ is the ratio of biomass growth of each sampled tree to its crown diameter (kg/decade/meter or lb/decade/ft).

Equations for estimating $\left(\frac{\Delta B}{C}\right)_i$ and $\left(\frac{\Delta M}{C}\right)_i$ in terms of aboveground biomass and cordwood are set forth in table 21. These regression equations were developed in the same manner as the growth equations for point sampling (table 11) and use the same set of input variables. Most of these equations have more than two input variables and cannot be presented satisfactorily in tabular form. They can be evaluated more efficiently by computer or programable calculator.

Two equations for pinyon basal area growth are included in table 21. The first is very precise (*CVR* = 4.4 percent), but the second is reasonably precise (*CVR* = 18.5 percent), easier to use, requires no measurements of crown diameter, and can be presented as a table (table 22).

In the following calculations of growth on the example transect, the regression estimates were calculated directly from the equations in table 21, using the sample data presented in the introductory section on line-intersect sampling. Estimated pinyon basal area growth is:

$$\frac{302.5}{L} \sum^{n} \left(\frac{\Delta B}{C}\right)_i = \frac{302.5}{100} \times (0.73 + 1.53 + 0.94) = 9.98 \text{ ft}^2\text{/acre/decade}$$

Table 21.--*Regression equations for estimating basal area, aboveground biomass, and cordwood growth rates of pinyon and juniper trees. The dependent variable* (Y) *is decadal growth divided by average crown diameter. The independent variables are as defined in table 11 except* Z, *which is* (H•Ds•Rs/1,000)

Equations	$\bar{Y}$	SDR	CVR	R^2
			Percent	
Metric				
Pinyon basal area growth/crown diameter	(cm^2/decade/m)			
$\hat{Y} = 3.980\frac{Rs \cdot Ds}{C} - 4.349\frac{Rs^2}{C} - 0.4554Rs^2 - 0.02916Rs \cdot Ds - 0.318$	30.67	1.35	4.40	0.995
$\hat{Y} = 11.12Rs + 1.517Rs^2 + 0.1543Rs \cdot Ds + 5.45$	30.67	5.67	18.5	.907
Pinyon total aboveground biomass growth/crown diameter	(kg/decade/m)			
$\hat{Y} = 14.07Z^{\frac{1}{2}} + 1.125Rs + 0.6325H \cdot Rs - 1.70$	12.17	1.98	16.3	.928
Pinyon cordwood growth/crown diameter	(kg/decade/m)			
$\hat{Y} = 28.90Z - 9.385Z^2 - 2.153Rs + 2.24$	6.51	1.69	25.9	.902
Juniper basal area growth/crown diameter	(cm^2/decade/m)			
$\hat{Y} = 2.991\frac{Db \cdot Rb}{C} + 17.22Rb - 1.872Rb^2 + 0.19$	31.20	4.92	15.8	.939
Juniper total aboveground biomass growth/crown diameter	(kg/decade/m)			
$\hat{Y} = 3.650Rb + 0.5363C \cdot Rb + 0.548$	7.66	1.79	23.4	.861
Juniper cordwood growth/crown diameter	(kg/decade/m)			
$\hat{Y} = 0.04466Db \cdot Rb + 0.06524Db \cdot Rb \cdot Sb^{-\frac{1}{2}} + 0.32$	2.51	0.423	25.1	.866
U.S.				
Pinyon basal area growth/crown diameter	(in^2/decade/ft)			
$\hat{Y} = 3.980\frac{Rs \cdot Ds}{C} - 4.349\frac{Rs^2}{C} - 0.1388Rs^2 - 0.00889Rs \cdot Ds - 0.015$	1.449	.064	4.40	.995
$\hat{Y} = 1.334Rs + 0.4624Rs^2 + 0.0470Rs \cdot Ds + 0.257$	1.449	.268	18.5	.907
Pinyon total aboveground biomass growth/crown diameter	(lb/decade/ft)			
$\hat{Y} = 13.26Z^{\frac{1}{2}} + 1.920Rs + 0.3291H \cdot Rs - 1.140$	8.18	1.33	16.3	.928
Pinyon cordwood growth/crown diameter	(lb/decade/ft)			
$\hat{Y} = 38.19Z - 24.39Z^2 - 3.675Rs + 1.504$	4.37	1.14	25.9	.902
Juniper basal area growth/crown diameter	(in^2/decade/ft)			
$\hat{Y} = 2.991\frac{Db \cdot Rb}{C} + 2.066Rb - 0.5706Rb^2 + 0.009$	1.474	0.232	15.8	.939
Juniper total aboveground biomass growth/crown diameter	(lb/decade/ft)			
$\hat{Y} = 6.230Rb + 0.2790C \cdot Rb + 0.368$	5.15	1.20	23.4	.861
Juniper cordwood growth/crown diameter	(lb/decade/ft)			
$\hat{Y} = 0.1936Db \cdot Rb + 0.2828Db \cdot Rb \cdot Sb^{-\frac{1}{2}} + 0.215$	1.69	0.423	25.1	.866

Table 22.--*Ratio of decadal basal area growth to average crown diameter as a function of decadal radial wood growth* (Rs) *and stump diameter of pinyon*

Rs	Stump diameter (inches) 8	12	16	20	24	28	32	36
Inches	- - - - - - - -	*Square inches per decade per foot*						- - - - - - - -
0.10	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.56
.15	.52	.55	.58	.61	.64	.66	.69	.72
.20	.62	.66	.69	.73	.77	.81	.84	.88
.25	.71	.76	.81	.85	.90	.95	1.00	1.04
.30	.81	.87	.92	.98	1.04	1.09	1.15	1.21
.35	.91	.98	1.04	1.11	1.18	1.24	1.31	1.37
.40	1.01	1.09	1.17	1.24	1.32	1.39	1.47	1.54
.45	1.12	1.20	1.29	1.37	1.46	1.54	1.63	1.71
.50	1.23	1.32	1.42	1.51	1.60	1.70	1.79	1.89
.55	1.34	1.44	1.54	1.65	1.75	1.85	1.96	2.06
.60	1.45	1.56	1.68	1.79	1.90	2.01	2.13	2.24
.65	1.56	1.69	1.81	1.93	2.05	2.17	2.30	2.42
.70	1.68	1.81	1.94	2.08	2.21	2.34	2.47	2.60
.75	1.80	1.94	2.08	2.22	2.36	2.50	2.65	2.79
.80	1.92	2.07	2.22	2.37	2.52	2.67	2.82	2.97
.85	2.04	2.20	2.36	2.52	2.68	2.84	3.00	3.16
.90	2.17	2.34	2.51	2.68	2.85	3.02	3.19	3.35
.95	2.30	2.48	2.66	2.83	3.01	3.19	3.37	3.55
1.00	2.43	2.62	2.81	2.99	3.18	3.37	3.56	3.75
1.05	2.56	2.76	2.96	3.15	3.35	3.55	3.75	3.94
1.10	2.70	2.90	3.11	3.32	3.52	3.73	3.94	4.15
1.15	2.84	3.05	3.27	3.48	3.70	3.92	4.13	4.35
1.20	2.97	3.20	3.43	3.65	3.88	4.10	4.33	4.55

The first juniper (tree no. 4) has a breast height diameter of 10 inches, an average crown diameter of 16 ft, and the average combined width (Rb) of the last 10 complete annual rings is 0.40 inches. Its basal area growth, according to the juniper basal area equation in table 21, is 1.49 inches^2/decade/ft of crown diameter. The second juniper has two stems at breast height, 6 and 7 inches in diameter, that are equivalent to a single stem 9 inches in diameter. Cores taken at breast height on the larger stem show a radial wood growth rate (Rb_1) of 0.35 inches per decade. This is corrected to an equivalent growth rate by:

$$Rb = \frac{Rb_1}{Db_1} \times \sqrt{Db_1^2 + Db_2^2 + \ldots Db_n^2} = \frac{0.35}{7} \times 9 = 0.45 \text{ inch/decade.}$$

The estimated basal area growth of the second juniper is 1.50 inches^2/decade/ft of crown diameter. Estimated juniper basal area growth at stump height is:

$$\frac{302.5}{100} \times (1.49 + 1.50) = 9.04 \text{ ft}^2\text{/acre/decade}$$

Combined estimated basal area growth on the example transect is 19.0 ft^2/acre/decade.

Estimated biomass growth rates on the sample transect are:

Pinyon total: 435.6 x (3.81 + 7.70 + 5.18) = 7,270 lb/acre/decade
Juniper total: 435.6 x (4.65 + 5.43) = 4,391 lb/acre/decade
Pinyon cordwood: 435.6 x (1.47 + 3.90 + 2.15) = 3,276 lb/acre/decade
Juniper cordwood: 435.6 x (2.12 + 1.81) = 1,712 lb/acre/decade.

In cubic volume, the estimated cordwood growth rate of pinyon and juniper combined is:

$$\frac{3{,}276 \text{ lb/acre}}{29 \text{ lb/ft}^3} + \frac{1{,}712 \text{ lb/acre}}{24 \text{ lb/ft}^3} = 184 \text{ ft}^3\text{/acre/decade}$$

The line-intersect method described here is theoretically correct only if the tree crowns are perfectly round. Irregular crowns introduce error. The mean error due to irregular crown shape is probably negligible except in stands where the maximum crown axes tend to be oriented in the same direction. In such stands, the bias can be reduced by laying out one-half of the lines perpendicular to the other half. In stands with very irregular crown shapes, the point method should be used if feasible.

DISCUSSION

The procedures apply to simple situations as well as the more complex. For example, to estimate the pinyon cordwood volume in a stand, it is only necessary to lay out a few transect lines and determine the heights and stump diameters of the intersected pinyon trees. The cordwood volume is estimated with a few simple calculations using table 15. The amount of slash that would be produced could also be estimated by using the stump diameter data and table 16. If an angle gage can be used, the procedure would involve determining crown diameters and heights of the trees tallied at the sampling points and using table 5 to calculate the estimated cordwood volume.

The biomass estimation tables are intended for the simpler sampling situations. For more complex or extensive inventories, computers or programable calculators should be programed to evaluate the regression equations and compute the estimates. Appendix B contains input and output data that could be used to verify programs.

Actual measurement of most of the input variables is usually not necessary for the experienced cruiser. Average crown diameter, stem diameter, and height can be estimated satisfactorily after adequate training and practice.

Decadal radial wood growth must be determined more precisely. One increment core is usually adequate on small trees with reasonably round stems. If the tree is on a slope, the core should be taken along the contour, rather than from the uphill or downhill side of the tree. Two cores should be taken from opposite sides of the stem on medium size trees with fairly round stems. Four cores should be taken (about 90° apart) from large trees and trees with badly out-of-round stems. The cores should be taken at stump height (15 cm or 6 inches) on pinyon and at breast height (137 cm or 54 inches) on junipers. The width of the 10 outermost complete rings on each core should be measured to the nearest 1 mm (or 1/20 inch) under a 7- or 10-power microscope. If more than one core is taken from a tree, the measured widths are averaged to obtain Rs or Rb.

The procedures and regression equations in this paper were developed specifically for singleleaf pinyon and for Utah juniper within the geographical range of singleleaf pinyon. The sampling procedures, however, are readily adaptable to other woodland species although the regression equations do not apply directly.

There are a number of ways to adapt these procedures to other species. One way is to develop new regression equations, similar to the ones in this paper, for the species to be sampled. Another, more rapid, way is to use the procedures and equations in this paper on similar species and apply correction factors.

For example, Colorado pinyon (*Pinus edulis*) could be sampled using the point or line-intersect procedures described for singleleaf pinyon if a subsample of the sample trees were selected for actual measurement of the attribute being inventoried. Specifically, if cordwood volume of Colorado pinyon were being inventoried, the following procedure could be used. The pounds per acre of cordwood would be estimated using the singleleaf pinyon equations and sampling methods (either point or line-intersect). In addition, the actual cubic foot volume of cordwood would be measured by dendrometer or by other means in a subsample of the selected trees (every 20th sample tree, perhaps).

If the point sampling method is used, the correction factor (Cf) would be:

$$Cf = \sum^{n} \frac{V_i}{B_i} \bigg/ \sum^{n} \left(\frac{\hat{W}}{B}\right)_i$$

in which V_i is the actual volume (ft^2) of each subsampled tree, B_i is the basal area (ft^2) of that tree, and $\left(\frac{\hat{W}}{B}\right)_i$ is the tree's estimated pounds of cordwood per square foot of basal area from table 5 or the cordwood equation in table 2.

If the line intercept method is used, the correction factor is:

$$Cf = \sum^{n} \frac{V_i}{C_i} \bigg/ \sum^{n} \left(\frac{\hat{W}}{C}\right)_i$$

in which C_i is the average crown diameter of the subsampled tree with volume V_i, and $\left(\frac{\hat{W}}{C}\right)_i$ is the tree's estimated pounds of cordwood per foot average crown diameter from table 15 or the cordwood equation in table 11.

This correction factor serves the dual purpose of correcting for variations between singleleaf and Colorado pinyon and converting pounds to cubic feet. The corrected stand volume would be calculated by multiplying the stand estimate in pounds or pounds per acre by the correction factor.

The general approach would be the same in metric units or with other species. This approach could also be used with singleleaf pinyon and Utah juniper to improve estimates by correcting for local variations.

PUBLICATIONS CITED

Bitterlich, W.
1947. Die Winkelzählmessung. Allg. Forst-u. Holzwirts. Zfg. 58:94-96.

Brown, J. K.
1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17(1): 96-102.

Budy, J. D., R. O. Meeuwig, and E. L. Miller.
1979. Aboveground biomass of singleleaf pinyon and Utah juniper. *In* Forest resource inventories. p. 943-953. W. E. Frayer, ed. Workshop Proc., Colorado State Univ., Fort Collins [July 23-26, 1979].

Canfield, R. H.
1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.

Clendenen, G. W.
1979. Gross cubic-volume equations and tables, outside bark, for pinyon and juniper trees in northern New Mexico. USDA For. Serv. Res. Pap. INT-228, 21 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Draper, N. R., and H. Smith.
1966. Applied regression analysis. 407 p. John Wiley and Sons, Inc., New York.

Estola, J. D.
1979. Preliminary pinyon-juniper volume tables. U.S. Dep. Interior, Bur. Land Manage. Resour. Inventory Notes BLM 18:6-8.

Freese, F.
1962. Elementary forest sampling. USDA For. Serv. Agric. Handb. 232, 91 p. (rev. 1971).

Grosenbaugh, L. R.
1952. Plotless timber estimates--new, fast, easy. J. For. 50:32-37.

Howell, J., Jr.
1937. Relation of crown diameter to cubic volume of one-seed juniper. J. For. 35:829-831.

Howell, J., Jr.
1940. Pinyon and juniper--a preliminary study of volume, growth and yield. USDA Soil Conserv. Serv., Reg. 8, Bull. 71, 90 p.

Howell, J., Jr., and B. R. Lexen.
1939. Volume tables for *Juniperus monosperma* and *Juniperus scopulorum*. USDA Soil Conserv. Serv., Reg. 8, Bull. 59, Woodland Ser. 8, 22 p.

Husch, B., C. I. Miller, and T. W. Beers.
1972. Forest mensuration, 2nd ed. 410 p. The Ronald Press Co., New York.

Meeuwig, R. O.
1977. Slope-compensating stick-type angle gage. South. J. Appl. For. 1(3):25-26.

Meeuwig, R. O.
1979. Growth characteristics of pinyon-juniper stands in the western Great Basin. USDA For. Serv. Res. Pap. INT-238, 22 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Meeuwig, R. O., and J. D. Budy.
1979. Pinyon growth characteristics in the Sweetwater Mountains. USDA For. Serv. Res. Pap. INT-227, 26 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Meeuwig, R. O., E. L. Miller, and J. D. Budy.
1978. Estimating pinyon-juniper cordwood with the line-intersect method. USDA For. Serv. Res. Note INT-242, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Meeuwig, R. O., E. L. Miller, and J. D. Budy.
1979. Estimating pinyon and juniper fuel and biomass from aerial photographs. USDA For. Serv. Res. Note INT-274, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Moessner, K. L.
1962. Preliminary aerial volume tables for pinyon-juniper stands. USDA For. Serv. Res. Pap. No. 69, 20 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Reveal, J. L.
1944. Single-leaf pinon and Utah juniper woodlands of western Nevada. J. For. 42:276-278.

Vries, P. G. de.
1973. A general theory on line intersect sampling with application to logging residue inventory. Med. Landbouw Hogeschool 73-11, Wageningen, The Netherlands. 23 p.

Warren, C. E., and P. F. Olsen.
1964. A line intersect technique for assessing logging waste. For. Sci. 10(3):267-276.

APPENDIX A

Sample Size and Sampling Error

For statistical purposes, the point estimates and line estimates can be treated in exactly the same way as estimates derived from fixed-size plots. The coefficient of variation ($C\%$) is calculated by dividing the standard deviation (s) of the individual point or line estimates by their mean ($\bar{x}$) and multiplying by 100.

$$C\% = \frac{s}{\bar{x}} \times 100$$

An estimate of the coefficient of variation is needed to determine the number of points or lines required to sample a stand within a chosen allowable sampling error percentage ($E\%$) of the expected mean. This estimate can be obtained from a preliminary survey or from previous experience in similar stands. The conventional equation for sample size (N) is:

$$N = \left(\frac{C\%}{E\%} \times t\right)^2$$

This equation requires iterative calculations because the value of "t" varies with the degrees of freedom that depend, in turn, on the value of N (Freese 1962). The following regression equation gives the same answers without iteration or the use of a "t" table:

$$N = a + b\left(\frac{C\%}{E\%}\right)^2$$

The regression coefficients (a and b) depend on the probability level chosen:

Probability level *Percent*	a	b
1	3.4	6.66
2	3.0	5.42
5	2.4	3.84
10	2.0	2.70
20	1.5	1.64
30	1.2	1.07
40	1.0	0.71
50	0.8	.46

These coefficients were calculated for each probability level by selecting five values of N and calculating values of $\left(\frac{C\%}{E\%}\right)^2$ that would yield precisely those values of N. For the 10 percent level of probability, the input data were:

(Y) N	$t_{0.10}$	(X) $\left(\frac{C\%}{E\%}\right)^2$
3	2.920	0.352
6	2.015	1.478
16	1.753	5.207
41	1.684	14.46
121	1.658	44.02

Simple linear regression of these data produced the coefficients given above for the 10 percent level of probability. The coefficients for the other probability levels were calculated with the same values of N and the appropriate values of t. The regression equations for all listed probability levels have an r^2 of at least 0.999 and will estimate N within one unit from $2<N<120$ or better.

For example, let us assume a 7-point (or line) survey of cordwood volume that yields the following point (or line) estimates: 650, 774, 867, 928, 1,023, 1,116, and 1,257 ft^3/acre. The mean value ($\bar{x}$) is 945 ft^3/acre and the standard deviation is 206 ft^3/acre.

$$C\% = \frac{s}{\bar{x}} \times 100 = \frac{206}{945} \times 100 = 21.8\%$$

If we choose the 10 percent level of probability, the sampling error is:

$$E\% = \frac{C\%}{\sqrt{N}} \times t_{.10} = \frac{21.8\%}{\sqrt{7}} \times 1.943 = 16.0\%$$

If we wish to reduce the sampling error to 10 percent, the number of samples required is:

$$N = a + b\left(\frac{C\%}{E\%}\right)^2 = 2 + 2.7 \left(\frac{21.8}{10}\right)^2 = 14.8$$

or, by the conventional equation:

$$N = \left(\frac{C\%}{E\%} \times t_{.10}\right)^2 = \left(\frac{21.8}{10} \times 1.761\right)^2 = 14.7$$

These results indicate that if there were no errors except those of sampling, the population mean would be within 16 percent of the sample mean (945 cubic feet per acre) unless a 1 in 10 chance had occurred, and that eight additional samples would reduce the sampling error to less than 10 percent.

APPENDIX B

Data for Program Testing

This appendix provides check data for verifying computer programs. The input data are for an average size pinyon and an average size juniper. The output data are the estimated values obtained from the respective regression equations using the input data. The data in metric units are not exactly equivalent to the data in U.S. units because of rounding.

SINGLELEAF PINYON

	Symbol	Metric		U.S.	
Input data					
Stem diameter stump height (15 cm or 6 inches)	Ds	30.5	cm	12	in
Crown diameter (average)	C	4.6	m	15	ft
Tree height (total)	H	6.7	m	22	ft
Width of 10 annual rings (stump height)	Rs	1.22	cm	0.48	in
Rs/Ds	X	0.040		0.040	
Ds•Rs•H/1000	Z	0.2493		0.1267	
Output data					
Aboveground biomass/basal area	T/B	3,325	kg/m^2	678	lb/ft^2
Cordwood/basal area	W/B	1,361	kg/m^2	278	lb/ft^2
Slash/basal area	S/B	2,007	kg/m^2	408	lb/ft^2
Fine fuels/basal area	FF/B	929	kg/m^2	189	lb/ft^2
Foliage/basal area	F/B	494	kg/m^2	100	lb/ft^2
Basal area growth/basal area	ΔB/B	1,814	$cm^2/decade/m^2$	0.181	$ft^2/decade/ft^2$
Aboveground biomass growth/basal area	ΔT/B	727	$kg/decade/m^2$	148	$lb/decade/ft^2$
Cordwood growth/basal area	ΔW/B	366	$kg/decade/m^2$	75	$lb/decade/ft^2$
Aboveground biomass/crown diameter	T/C	54.32	kg/m	36.49	lb/ft
Cordwood/crown diameter	W/C	22.49	kg/m	15.12	lb/ft
Slash/crown diameter	S/C	32.39	kg/m	21.74	lb/ft
Fine fuels/crown diameter	FF/C	14.50	kg/m	9.74	lb/ft
Foliage/crown diameter	F/C	8.40	kg/m	5.65	lb/ft
Basal area/crown diameter	B/C	159	cm^2/m	7.54	in^2/ft
Basal area growth/crown diameter	ΔB/C	28.7	$cm^2/decade/m$	1.36	$in^2/decade/ft$
Aboveground biomass growth/crown diameter	ΔT/C	11.87	kg/decade/m	7.98	lb/decade/ft
Cordwood growth/crown diameter	ΔW/C	6.23	kg/decade/m	4.19	lb/decade/ft

UTAH JUNIPER

	Symbol	Metric		U.S.	
Input Data					
Stem diameter breast height (137 cm or 4.5 ft)	Db	20	cm	8	in
Crown diameter (average)	C	4	m	13	ft
Width of 10 annual rings at breast height	Rb	1	cm	0.4	in
Number of stems at breast height	Sb	2		2	
Output data					
Aboveground biomass/crown area	T/CA	10.43	kg/m^2	2.172	lb/ft^2
Cordwood/crown area	W/CA	2.69	kg/m^2	0.573	lb/ft^2
Slash/crown area	S/CA	7.31	kg/m^2	1.515	lb/ft^2
Fine fuels/crown area	FF/CA	3.93	kg/m^2	0.817	lb/ft^2
Foliage/crown area	F/CA	3.13	kg/m^2	0.649	lb/ft^2
Basal area/crown area	B/CA	53.6	cm^2/m^2	239	ft^2/acre
Basal area growth/crown area	ΔB/CA	9.00	$cm^2/decade/m^2$	40.7	ft^2/decade/acre
Aboveground biomass growth/crown area	ΔT/CA	2.22	$kg/decade/m^2$	0.464	$lb/decade/ft^2$
Cordwood growth/crown area	ΔW/CA	0.686	$kg/decade/m^2$	0.147	$lb/decade/ft^2$
Aboveground biomass/crown diameter	T/C	33.01	kg/m	22.39	lb/ft
Cordwood/crown diameter	W/C	9.48	kg/m	6.55	lb/ft
Slash/crown diameter	S/C	23.75	kg/m	16.02	lb/ft
Fine fuels/crown diameter	FF/C	12.65	kg/m	8.54	lb/ft
Foliage/crown diameter	F/C	10.08	kg/m	6.83	lb/ft
Basal area/crown diameter	B/C	166	cm^2/m	7.93	in^2/ft
Basal area growth/crown diameter	ΔB/C	30.5	cm^2/decade/m	1.48	in^2/decade/ft
Aboveground biomass growth/crown diameter	ΔT/C	6.34	kg/decade/m	4.31	lb/decade/ft
Cordwood growth/crown diameter	ΔW/C	2.14	kg/decade/m	1.47	lb/decade/ft

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980—777-028/70 Region No. 8

Meeuwig, Richard O., and Jerry D. Budy.
1981. Point and line-intersect sampling in pinyon-juniper woodlands. USDA For. Serv. Gen. Tech. Rep. INT-104, 38 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Two probability proportional to size (p.p.s.) sampling methods have been adapted for use in pinyon-juniper woodlands. Procedures are described for estimating biomass, stand basal area, canopy cover, tree density, and growth rates using either point sampling or line-intersect sampling. Both sampling methods are supported by regression equations for estimating aboveground biomass, cordwood, slash, fine fuels, and foliage of singleleaf pinyon and Utah juniper. Regression equations for predicting decadal growth rates in terms of stand basal area, aboveground biomass, and cordwood are also presented.

KEYWORDS: pinyon, juniper, sampling methods, line-intersect, Bitterlich, inventory, growth

Meeuwig, Richard O., and Jerry D. Budy.
1981. Point and line-intersect sampling in pinyon-juniper woodlands. USDA For. Serv. Gen. Tech. Rep. INT-104, 38 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Two probability proportional to size (p.p.s.) sampling methods have been adapted for use in pinyon-juniper woodlands. Procedures are described for estimating biomass, stand basal area, canopy cover, tree density, and growth rates using either point sampling or line-intersect sampling. Both sampling methods are supported by regression equations for estimating aboveground biomass, cordwood, slash, fine fuels, and foliage of singleleaf pinyon and Utah juniper. Regression equations for predicting decadal growth rates in terms of stand basal area, aboveground biomass, and cordwood are also presented.

KEYWORDS: pinyon, juniper, sampling methods, line-intersect, Bitterlich, inventory, growth

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)